NASA CR 102056

DEVELOPMENT OF A COMPUTER PROGRAM FOR
DETERMINING EXTERNAL RADIATION ABSORBED
BY THE APOLLO SPACECRAFT

by

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FINAL USER'S MANUAL
1 March 1965 - 1 June 1966

Contract No. NAS9-3800

MRI Project No. 2846-E

For

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PREFACE

This Final User's Manual describes a computer program that was developed during the period 1 March 1965 to 1 April 1966 for the project entitled, "Development of a Computer Program for Determining External Radiation Absorbed by the Apollo Spacecraft." The work was authorized 16 February 1965 by the NASA Manned Spacecraft Center under Contract NAS9-3860, and has been performed by Midwest Research Institute, Kansas City, Missouri, under Project No. 2846-E.

Mr. Harold L. Finch was the project leader. Mr. Duncan Sommerville supervised the programming. Other principal investigators were Messrs. Michael Noland, Brook Sandford, Roger Schroeder and Gary Wages.

Mr. Robert Vogt was the NASA Project Engineer for the first six months; Mr. Edward Chimenti served in this capacity for the duration of the project.

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21 June 1966

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LIST OF SYMBOLS

a_m	Value of α_s subject to modification by f_s and g .
b_m	Function giving temperature dependence of α_p .
DEC	Declination or latitute of sun w.r.t. X_c, Y_c, Z_c axes (see Fig. C-3).
f_p	Function giving time dependence of α_p .
f_s	Function giving time dependence of α_s .
g	Function giving dependence on angle of incidence for α_s .
G	Gravitational constant.
i	Inclination of orbit plane (see Fig. C-4).
m	Material code.
M_p	Mass of planet.
RA	Right ascension or longitude of sun w.r.t. X_c, Y_c, Z_c axes (see Fig. C-3).
t	Time.
T	Temperature.
X_b, Y_b, Z_b	Coordinate axes in the body coordinate system (see Appendix D).
X_c, Y_c, Z_c	Coordinate axes in the celestial coordinate system (see Appendix D).
X_p, Y_p, Z_p	Coordinate axes in the planet coordinate system (see Appendix D).
X_v, Y_v, Z_v	Coordinate axes in the vehicle-orientation coordinate system (see Appendix D).
α	Angle between planet-sun line and X_p axis (see Fig. C-3).
α_p	Absorptivity of coating material w.r.t. planet radiation.
α_s	Absorptivity of coating material w.r.t. solar radiation.
β	Angle between planet-sun line and Z_p axis (see Fig. C-3).
γ	Angle between planet-sun line and Y_p axis (see Fig. C-3).
δ	Angle between vehicle-sun line and vehicle-element line.
ε	Angle between vehicle-planet line and vehicle-element line.

η	Vehicle yaw angle (see Fig. C-5).
θ_s	Angle between sun-planet line and planet-vehicle line.
Λ_n	Angle between X_b axis and projection of vehicle-node line on the plane $Z_b = 0$ (see Fig. C-1).
Λ_r	Angle between X_b axis and projection of vehicle rotation axis on the plane $Z_b = 0$ (see Fig. C-6).
ρ	Vehicle roll angle (see Fig. C-5).
Σ	Angle measured counterclockwise about Z_p from X_p axis to the projection of sun-planet line on the plane $Z_p = 0$ (see Fig. C-3).
ϕ	True anomaly (see Fig. C-2).
$\Delta\phi$	The increment of ϕ between points where heat loads are computed for orbital missions.
ϕ_{in}	Value of ϕ where vehicle passes into the planet's shadow.
ϕ_{out}	Value of ϕ where vehicle passes out of the planet's shadow.
ϕ_c	Angle between plane defined by the vehicle, planet and sun, and the plane defined by the vehicle, planet and vehicle node.
ψ	Vehicle pitch angle (see Fig. C-5).
Ω	Longitude of ascending node -- measured counterclockwise about Z_c from X_c to the line of nodes (see Fig. C-4).
Ω_n	Angle between Z_b axis and vehicle-node line (see Fig. C-1).
Ω_r	Angle between Z_b axis and vehicle rotation axis (see Fig. C-6).
ω	Argument of perifocus -- measured in the orbit plane in the direction of travel from the line of nodes to the perigee (see Fig. C-4).
ω_r	Rate of vehicle rotation.

SUMMARY

The computer program described in this User's Manual was developed to determine the total absorbed thermal radiation by spacecraft during orbital missions and during missions that are defined by tape.* It was written by Midwest Research Institute (MRI) for the National Aeronautics and Space Administration's Manned Spacecraft Center (NASA-MSC). The program is a major modification and expansion of the computer program previously written by MRI under Contract No. NAS9-1059.[1] The latest version was designed especially for lunar missions of the Apollo, but it also is applicable to interplanetary missions and to other spacecraft.

The major features and capabilities of the program are listed below:

1. Up to 1,000 spacecraft surface areas (nodes) may be thermally analyzed in a given mission;

2. Required geometric data for 950 Apollo nodes are coded and stored within the program;

3. The effects of shadowing due to other parts of the spacecraft structure may be included in the analyses for six basic Apollo configurations;

4. The spacecraft may be oriented toward the sun, a planet, the moon, or a star;

5. The spacecraft may be given roll, pitch, and yaw attitudes relative to a basic orientation coordinate system;

6. The spacecraft may be made to rotate at a specified rate about any axis;

7. The flight path may be either an elliptical orbit about any planet or the moon, or it may be any mission about or between two such bodies;

8. Required planet property data for the moon and the planets are stored within the program;

9. Required ephemeris data may be either read in as input or computed for a specified date;

* Hereafter, missions that are defined by tape will be referred to as trajectory tape missions.

10. Most of the data (e.g., type of orientation) may be changed instantaneously at any specified time throughout the mission;

11. The planet's surface temperature may be considered to be either uniformly distributed or variable or local temperature may be specified;

12. Additional Apollo node arrangements may be analyzed by lumping together any of the 950 basic nodes; and

13. The program output may be printed and/or plotted; the results may also be punched at such time that the format is specified and incorporated into the output routine. The applicable computers (see below) have no provisions for variable input/output formats in FORTRAN IV.

Most of the program testing and debugging was carried out on a Univac 1107 computer in FORTRAN IV. Since FORTRAN IV under EXEC II is essentially the same for both the 1107 and 1108, the program should run equally well on either machine. Final versions were written for the Univac computer and for the IBM 7094/7040 Direct Coupled System (IBM-DCS), and both were thoroughly tested at the NASA-MSC computational center.

I. INTRODUCTION

A computer program to determine the total absorbed thermal radiation by spacecraft during orbital and trajectory tape missions has been developed under Contract No. NAS9-3860 by Midwest Research Institute (MRI) for the National Aeronautics and Space Administration's Manned Spacecraft Center (NASA-MSC). The program is a major modification and expansion of the computer program previously written by MRI under Contract No. NAS9-1059.[1] The latest version was designed especially for lunar missions of the Apollo, but is also applicable to interplanetary missions and to other spacecraft. The program can simultaneously analyze up to 950 Apollo surface areas (nodes) taking into account the effects of shadows cast by other parts of the vehicle structure.

Most of the program testing and debugging was carried out on a Univac 1107 computer in FORTRAN IV. Final versions were written for this machine and for the IBM 7094/7040 Direct Coupled System (IBM-DCS), and both were thoroughly tested at the NASA-MSC computational center.

This Final User's Manual summarizes the program and its use. Operating instructions are given in Section II, general descriptions of data and comment cards are given in Section III, and detailed descriptions of typical data and comment cards are given in Section IV. The program output is described in Section V.

The appendices contain illustrations of input parameters, flow charts, and other pertinent information to facilitate the effective use of the program. The Final Project Report,[2] which describes the theory upon which the program is based, supplements this manual.

II. OPERATING INSTRUCTIONS

The program has been checked out on the Univac 1107 and on the IBM-DCS. Since the 1107 has been taken out of service at the NASA-MSC computational center, the following instructions are written for the 1108.

A. Running on the Univac 1108

The program is most easily run on the Univac 1108 by loading it from tape. The control cards necessary to accomplish this are described below. The tape containing the program is assigned to unit A; if shadow logic is required, the shadow factor tape for the Apollo is requested and assigned to unit G; for trajectory tape missions, the tape is assigned to unit I.

Card 1 is the standard $JOB card. The other control cards are as follows:

Card No.	Col 1	Col 8	Col 16
2	7	ASG	A = 8584[a]
3[b]	7	ASG	G = 373 (optional)[a]
4[c]	7	ASG	I = TRAJEC[d] (optional)
5	7	XQT	CUR
6		TRW	A
7		IN	A
8		TRI	A
9	7N	XQT	F119

where 7 denotes a 7 - 8 multiple punch.

The data deck comes next and includes data for as many cases as desired. Data for each case consist of one or more cards containing numerical data and/or comments followed by a blank card indicating the end of case data. For cases after the first, only the cards which contain data that differ from the previous case need be read. Due to the increased versatility of the program, it is now required that the entire card be punched (where applicable) instead of only punching the data that are being changed. An extra blank followed by a card with 7 EOF in columns 1 - 5 must follow the data for the last case. Data and comment cards are described in Section III.

B. Running on the IBM-DCS

To run on the DCS under IBSYS, up to four control cards are used. Card 1 is the standard $JOB card; the others are as follows:

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a/ The numbers 8584 and 373 are NASA-MSC tape designations.

b/ Card 3 may be omitted if the user does not wish to include the effects of shadows in any of the cases. In this case, all of the 01 data cards used must have zero or a blank in column 78 (see Section III-B).

c/ Card 4 may be omitted if no trajectory tape will be needed, i.e., if all cases to be run are orbital missions.

d/ The actual tape reel number should be used rather than the symbol, TRAJEC.

Card No.	Col 1	Col 8	Col 16
2[a]	$SETUP	9	BLOCK (7943) (optional)[b]
3[c]	$SETUP	11	BLOCK (TRAJEC)[d] (optional)
4	$IBJOB	-	GO, NO SOURCE

The object deck comes next followed by the deck of $ORIGIN and $INCLUDE cards which control overlay. Finally a $DATA is used to signal the beginning of the data deck. Following the data for the last case, an extra blank card is required followed by an end-of-file tab card.

If the program is put into the NASA program library, all cards from card 4 ($IBJOB) through the last of the $INCLUDE cards may be replaced with a single $PGLIBE card giving the library name assigned to the program.

C. Input/Output Units Referenced by the Program

The program refers to the input/output units listed below. Scratch tapes 4, 8, 10, 12 and 13 are simulated on drum or disk storage on the NASA Univac 1108 and DCS systems. If the program should be adapted for a standard IBM 7094, actual tapes would need to be mounted for each of these units.

Logical No.	Format	Words per Record	Type	Use
4	BCD	14	Scratch	Contains edited input deck
5	BCD	14	Input	Principal input
6	BCD	22	Output	Principal output
8	Bin.	252	Scratch	Contains intermediate data to be plotted
9	Bin.	190	Input	Shadow factor tape
10	BCD	14	Scratch	Temporary storage for 01 - 07 cards
11	Bin.	19	Input	Trajectory tape
12	BCD	14	Scratch	Temporary storage for 09 cards
13	BCD	14	Scratch	Temporary storage for 10 cards
17	Bin.	-	Output	Output from program to SC-4020

a/ Card 2 may be omitted if none of the cases to be run require tables of shadow factors for the Apollo.

b/ The number 7943 is a NASA-MSC tape designation.

c/ Card 3 may be omitted if no trajectory tape will be needed, i.e., if all cases to be run are orbital missions.

d/ The actual tape reel number should be used rather than the symbol, TRAJEC.

III. GENERAL DESCRIPTIONS OF DATA AND COMMENT CARDS

The type of each data and comment card is indicated by the card code in columns 1 and 2. The following types may be used:

Card Code	Type of Card
10	Comment
01	Case number and control information
02	Orientation and rotation
03	Planet
04	Mission
05	Sun position
06	Redefinition
07	Low altitude planet temperature
09	Element
08	Trajectory continuation

The data cards require that decimal points be punched for numbers in fields between columns 13 and 76. Outside this range, decimal points should not be used and the numbers must be right justified in their fields. The above cards, with the exception of No. 10, are read with the following format: FORMAT (I2, 2I3, I4, 8E8.1, I2, 2I1). It should be noted that if a decimal point is punched in any 8 column E field, exponents are not needed unless the magnitude of the number is extremely small or extremely large.

It is recommended that the cards be used in the order listed above unless otherwise specified in the following paragraphs which describe each type of card. More than one 06, 09 and 10 cards are allowable.

Values read in for one case remain defined until superseded by another card containing the same type of information. Exceptions to this rule are the 10 card and the 08 card.

General descriptions of the various card types follow. Additional clarification is provided by examples given in Section IV. For the user's convenience, a reference guide to input data preparation is given in Appendix J.

A. Comment (10 Card)

Comment cards may have alphameric characters in columns 3 - 72. The first comment card is used as a heading for each page of output for orbital missions. For trajectory tape missions, an identification record from the trajectory tape is used as the page heading. All comments (any number from 0 to 18) will be listed at the beginning of the first page of printed output for each case and on the first plot frame if plots are requested.

Comments may also be printed to coincide with an instantaneous change (e.g., a change from star to sun-orientation) during a trajectory tape mission. Preparation of comments for this special condition is described in Section III-J.

B. Case Number and Control Information (01 Card)

Columns 3 - 5 contain the case number. Columns 9 - 12 contain the number of elements to be analyzed. This number should be between 1 and 1,000 inclusive. For orbital cases, columns 13 - 20 contain ϕ_o , the initial value of true anomaly and columns 21 - 28 contain $\Delta\phi$, the increment of true anomaly at which heat fluxes are computed. For trajectory tape cases, columns 13 - 28 do not apply and are left blank. Column 78 should contain the configuration number (see Fig. C-10) if the Apollo shadow factors stored on tape are required for this case. A blank or zero can be used in column 78 if no shadow factors are needed. However, whenever a valid configuration code is used in column 78, it is necessary that the shadow tape be mounted. A one (1) in column 79 causes incident heats as well as absorbed heats to be printed. If column 79 contains zero (0) or blank, only absorbed heats are printed. A one (1) in column 80 causes the program to print the product of heat flux and element area in BTU/hr. If column 80 contains zero (0) or blank, the fluxes in BTU/hr-ft^2 are printed.

If any of the program parameters are to be changed during a trajectory tape mission, the first time in minutes at which they are to be instantaneously changed is contained (with decimal point) in columns 37 - 44 (see Section III-J).

C. Orientation and Rotation (02 Card)

Columns 9 - 12 contain the orientation code, namely, one (+1) for planet-oriented, minus one (-1) for sun-oriented, minus two (-2) for star-oriented, and zero (0) for rapid spinning about random axes. Columns 13 - 20 contain ρ , the roll angle; 21 - 28 contain ψ , the pitch angle; and 29 - 36 contain η , the yaw angle. These three angles are all in degrees. If the vehicle is star-oriented, the direction of orientation is given by a vector with the X , Y , and Z components contained in columns 45 - 52, 53 - 60, and 61 - 68, respectively. Since only the direction is obtained from these numbers, the components are nondimensional and a scale factor may be used to bring the three numbers into suitable range. The components must be in the planet coordinate system for orbital missions and in the conventional earth equatorial system with origin at the center of the planet and X directed toward Aries for trajectory tape missions.

If a rotary vehicle motion about some axis thru the origin of the body coordinate system is desired, the rate of rotation in revolutions per hour should be punched in columns 37 - 44. The decimal point should be included. The axis of rotation is given by a vector from the origin to an imaginary vehicle element whose location is given, in the body coordinate system, by the angles Ω_r and Λ_r . The rotation is taken to be in the sense which would cause a right hand screw to move along this axis from the origin toward the "element." The angles Ω_r and Λ_r in degrees must be punched in columns 3 - 5 and 6 - 8, respectively, of the 02 card. They must be right justified in the fields and decimal points must be omitted.

D. Planet (03 Card)

If a number from 1 - 9 is punched in column 5, the program will assign planet data according to the following: 1. - Earth, 2. - Moon, 3. - Jupiter, 4. - Mars, 5. - Mercury, 6. - Neptune, 7. - Saturn, 8. - Uranus, and 9. - Venus. Appendix E has a table of these data. If a zero (0) or a blank is in column 5, then columns 13 - 20 should contain distance from the sun in nautical miles; 21 - 28, the planet radius in nautical miles: 29 - 36, planet albedo; 37 - 44, the mass factor GM_p in ft^3/sec^2, and 45 - 52, the planet cold side temperature in degrees Rankine.

The planet data are used by the program in two ways: it specifies the planet of orientation if the vehicle is planet-oriented and it specifies the planet which is used in computing planet and albedo heat loads. For trajectory tape missions the planet code used must agree with either column 9 or 10 of the associated 04 card.

If column 8 contains a one (1), planet temperature will be taken as variable. Otherwise, it will be assumed to be constant.

E. Mission (04 Card)

This card is used to specify the type of mission, that is, whether it is an orbital or a trajectory tape mission. It also includes data that fully describe the orbit or trajectory.

If the mission is orbital, a one (1) is punched in column 5. Columns 6 - 8 contain the number of degrees of true anomaly to be covered by the program. [illegible] 360, a complete orbit will be run. Columns 13 - 20 and 21 - [illegible]al altitude in nautical miles at apogee and perigee, [illegible]

If [illegible]on is to be read from a trajectory tape rather than computed [illegible]nics relationships, column 5 of the 04 card should contain [illegible], and columns 9 and 10 should contain one (1) and two (2), [illegible] punches in columns 9 and 10 represent the planet codes of [illegible] "second" planets referenced on the trajectory tape, and must [illegible] moon if the trajectories are generated by the version of [illegible] trajectory program in use in March 1966. For trajectory [illegible]nets other than earth and moon, a new program interface must [illegible] accommodate the new trajectory format (see Appendix I).

[illegible]ify changes in the planet of reference or in several other [illegible] using an 08 card followed by the data cards necessary to [illegible] (see Section III-J).

F. Sun [illegible]

[illegible]icable only to orbital missions (i.e., all but trajectory [illegible] Column 5 contains a code number which indicates the form [illegible]osition is specified. If this is a two (2), then columns 13 - [illegible] and columns 21 - 28 contain β.* If column 5 contains [illegible] columns 13 - 20 contain α, 21 - 28 contain β, and 29 - [illegible] If column 5 contains a five (5), then columns 13 - 20 contain [illegible] 28 contain angle ω, 29 - 36 contain angle Ω, 37 - 44 [illegible]sion, and 45 - 52 contain declination. All angles are in [illegible]

If [illegible]ains a one (1), the program will read ϕ_{in} and ϕ_{out} [illegible] and 69 - 76, respectively. Otherwise ϕ_{in} and ϕ_{out} will [illegible]

[illegible]so specify the date and time instead of defining the sun's [illegible] the above methods. This can be done as follows:

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* For [illegible]bols, see the illustrations in Appendix C; also refer to [illegible] (see Ref. 2).

Column	Contents
1 and 2	05
5	1
13 - 20	angle i
21 - 28	angle ω
29 - 36	angle Ω
37 - 44	year (1900. to 2099.)
45 - 52	month (1. to 12.)
53 - 60	day (1. to 31.)
61 - 68	hours (0. to 23.)
69 - 76	minutes (less than 60.)

This feature is intended primarily for earth and moon orbits, but it will also work for the inner planets, Mercury, Venus and Mars.

G. Redefinition (06 Card)

The thermal absorptivity of any vehicle surface element can be specified to depend on the material, temperature of radiation source, angle of incidence of radiation, and length of time of exposure of the surface. If the radiation source is the sun, then dependence on radiation source temperature is neglected; if the source is the planet, the program neglects dependence on angle of incidence of radiation. Thus, the program uses separate formulas for determining absorptivity for solar and planet radiation, namely,

$$\alpha_s(m,\delta,t) = a_m \cdot f_s(t) \cdot g(\delta) \tag{1}$$

and

$$\alpha_p(m,T,t) = b_m(T) \cdot f_p(t) \tag{2}$$

respectively, where t is elapsed time in minutes, T is temperature in degrees Rankine, δ is angle of incidence in degrees, and m is the material code.

To specify α_s and α_p it is necessary to define the functions $f_s(t)$, $f_p(t)$, $g(\delta)$, $b_m(T)$ and the value a_m, as well as to create a cross reference between m, a number used as material code, and these functions. Unless the user specifies nonzero cross references $f_s(t)$, $f_p(t)$ and $g(\delta)$ are taken to be unity.

The program can store up to sixteen each of tables of f_s versus t, f_p versus t, g versus δ, and b_m versus T. There are also tables of cross references indicating for each given material code (from 1 to 16) which table of f_s, f_p and g are to be used in computing the overall absorptivities. If the cross reference is zero (0), the function is taken to be unity and the program skips the interpolations carried out otherwise. If the same function is to apply to more than one material, the same table for both materials can be referenced rather than reading in the table twice.

Tables of properties which are expected to be used frequently can be compiled into the program[a/] along with cross reference tables tying material codes to properties as part of the BLOCK DATA program B3DATA. However, any of these compiled values can be modified at execution time using 06 cards. The solar constant may also be changed in this way. Each 06 card must contain a code in columns 11 - 12 telling what type of data the card contains. The possible codes and their meanings are shown in the following table.

Columns 11 - 12	Type of Data
03	Entries in table of f_s versus t for material m[b/]
04	Entries in table of f_p versus t for material m
05	Entries in table of g versus δ for material m
06	Entries in table of b_m versus T for material m
07	A cross reference assigning a table of $f_p(t)$ to material m
08	A cross reference assigning a table of $f_s(t)$ to material m
09	A cross reference assigning a table of $g(\delta)$ to material m
10	Solar constant
11	Values of absorptivity for solar radiation (a_m) for one or more m

For 06 cards with columns 11 - 12 containing 07, 08 or 09, the material code should be punched in columns 4 - 5 and the number of the corresponding table to be cross referenced should be in columns 7 - 8. If a table number associated with a material code is zero (0), the corresponding factor is omitted from the expression for absorptivity.

If columns 11 - 12 of the 06 card contain 11, then columns 4 - 5 give the number, m, of the first material on the card for which a value of a_m is to be stored, and columns 7 - 8 give the last such number. Actual values of a_m are punched in eight-column fields: 13 - 20, 21 - 28, 29 - 36, 37 - 44, 45 - 52, 53 - 60, 61 - 68, and 69 - 76. If more than eight values are to be read, two 06 cards must be used.

If columns 11 - 12 of an 06 card contain 10, then the solar constant in units of BTU/hr-ft^2 is read from columns 13 - 20 of the card.

a/ See Appendix F for values currently stored within the program.
b/ Material m is specified in column 78.

For 06 cards having either 03,04, 05 or 06 in columns 11 - 12, the number of the table where data from the card will be stored is punched in columns 77 - 78. This must be a number from 1 to 16. The numbers in columns 4 - 5 and 7 - 8 are indices of the first and last numbers of the table to be read from the card. The structure of each type of table is discussed individually in the following paragraphs. Actual table entries are punched in the eight, 8-column fields beginning with 13 - 20.

The tables of f_s versus t and f_p versus t contain alternate values of t and f, e.g., t_o, $f(t_o)$, t_1, $f(t_1)$, t_2, $f(t_2)$, t_3, $f(t_3)$, t_4 and $f(t_4)$. The arrays have a dimension of 10 and will consequently hold only five points. Times must be in minutes and are related to values of time read from trajectory tapes or computed for elliptical orbits. Since a single 06 card can hold only eight floating point numbers, two are required if all ten table entries are to be read in. The program interpolates for f if $t_o < t < t_4$, but for $t < t_o$ or $t_4 < t$ the values of $f(t_o)$ or $f(t_4)$ are used.

The tables of g versus δ contain only the values of g. Values of δ are understood to range from 0° to 90° in increments of 10°. Here again, if all 10 values of g are to be read in, two cards are needed since a single 06 card can hold no more than eight floating point numbers.

Finally, the tables of b_m versus temperature, T, alternately contain values of T and b_m, the first entry being T_o, the next b_m for $T = T_o$, etc. Each succeeding pair of values gives a new point of the b_m versus T table. The table terminates with an entry for 10,000°R. However, no more than twenty values of b_m may be stored. The indices of the first and last values to be stored from a given card are given in columns 3 - 5 and 6 - 8, respectively. For example, if columns 3 - 8 read 001006, then the first six values of the table will be stored, namely T_o, $b_m(0)$, T_1, $b_m(T_1)$, T_2, $b_m(T_2)$.

H. Low Altitude Planet Temperature (07 Card)

If an 07 card is read, columns 13 - 20 will be stored as a critical low altitude in nautical miles, below which calculation of planet temperature by the program will be suspended. In this case, the program uses as planet temperature, °R, the number punched in columns 21 - 28.

I. Element (09 Card)

The present program will calculate heat fluxes for up to 1,000 elements per case. The actual number is given on the 01 card. Each element desired is entered on an 09 card and is given a sequence number in columns 3 - 5. These numbers must begin with one (1) and increase sequentially so that the sequence number of the last element is the same as the number of elements desired.

If columns 6 - 8 contain a valid node number (1 - 950), element area and location are taken from internal tables for the Apollo (see Appendices A and B). If a one (1) is punched in column 79, shadow logic and experimentally determined shadow data corresponding to the 950 nodes will be used by the program. If a zero (0) or blank is punched in column 79, shadow logic will be suppressed. It is also possible to modify the Apollo nodal parameters (area, Λ_n , Ω_n) and still use the stored shadow data; this can be done by punching the modified values as follows: Λ_n in columns 13 - 20, Ω_n in columns 21 - 28, and area in columns 29 - 36. Angles must be in degrees and area in square feet. Then if a floating point one (1.) is punched in columns 45 - 52, the program uses the value read on the card for Λ_n instead of the one furnished by the program. Similarly, a one (1.) in columns 53 - 60 and 61 - 68 causes the program to use corresponding values punched on the card for Ω_n and area, respectively.

If 6 - 8 does not contain a valid node number, element area is read from columns 29 - 36, and the angular coordinates Λ_n and Ω_n are read from 13 - 20 and 21 - 28, respectively. In this case shadow logic is not applicable and is not used.

Columns 9 - 12 should contain a nonzero numerical label which will identify the element in the output listing. Columns 9 - 12 may contain zero (0) or blanks (provided columns 6 - 8 contain a valid node number), in which case, the program sets the label equal to the node number used in columns 6 - 8.

If the element being defined is to be lumped with the subsequent element (one having the number in columns 3 - 5 increased by one), then columns 37 - 44 should contain the label again, including a decimal point in this field for format compatibility. This label is the same number as is in columns 9 - 12 unless they are blank, in which case, the label is in columns 6 - 8.

There is a restriction on element lumping which is due to the fact that computer storage is not sufficient to hold shadow tables for all the elements at the same time. Consequently, when more than 200 elements are analyzed, the program subdivides the problem. It is therefore illegal to have the sequenced numbers (not the node number) of the first element of a group to be lumped less than or equal to 200 while the sequence number of the last of the group is greater than 200. The same restriction holds for any multiple of 200; i.e., for 400, 600 and 800.

Columns 77 - 78 contain the number of the coating material specified for the element. Materials 1 to 6 are defined as described in Appendix F. These may be redefined or materials 7 to 16 may be defined using redefinition cards (06 cards).

If it is desired to have the absorbed heats expressed in graphical form by the plotter, a one (1) must be punched in column 80 of the applicable 09 (element) card. A blank or zero (0) in column 80 causes the plots to be deleted.

J. Trajectory Continuation (08 Card)

The user may modify the initial conditions for a trajectory tape mission by performing the following steps:

1. Punching a cutoff time in minutes into columns 37 - 44 of the 01 card (see Section III-B);

2. Placing an 08 card immediately after the last data card; and

3. Placing data cards containing the modified conditions immediately after the 08 card.

Descriptions of the 08 card and of the modified data cards follow:

The 08 card, which is used in place of the end-of-case blank card, signifies that the original data are to be modified. The 08 card may also be used to specify a new cutoff time - a time at which the case data will again be modified. If a new cutoff time is to be specified, the desired time should be punched in columns 13 - 20. When this time is reached, a blank card can be used to terminate the case, or another 08 card can be used to continue it as before.

Following the 08 card, data cards may be read to modify such information as configuration, planet, orientation, rotary motion, roll, pitch, yaw, etc. These cards must consist of one or more of the following types: 01, 02, 03 and 10. The planet specified must always be either the primary or secondary planet of the trajectory being used.

Comments may be used following each 08 card to provide messages in the output describing what program parameters are changed. The combination of 08 cards and comments (10 cards) may also be used to flag significant features of the trajectory which do not coincide with any program parameter changes, such as the point where the vehicle leaves earth orbit and begins the translunar part of its flight.

Finally the user may terminate the mission at any of the cutoff times by using an end-of-case blank card instead of the 08 card and the succeeding data cards. In this case, the program will compute until the cutoff time is reached and will then terminate the case and rewind the trajectory tape.

IV. EXAMPLES OF DATA AND COMMENT CARDS

Some of the input data options in the program are most easily understood by considering sample cases. This section gives examples of each type of input card and discusses how each is interpreted by the program. Data for these cards are illustrated in Fig. 1. These are isolated examples and each is independent of the context except where otherwise specified.

A. Comment (10 Card)

Example A is a dummy comment such as might be used in a trajectory tape mission to "save" a line for the identification furnished by the trajectory tape. For orbital missions, card A would cause each page of heat tables printed to have a blank line instead of a comment at the top.

Example B is an ordinary comment. If A and B occur together in a trajectory tape mission, the message on B will appear as the second line of identification on each frame of any plots generated.

B. Case Number and Control Information (01 Card)

Example C is for use with an orbital mission since ϕ_o of 45° and $\Delta\phi$ of 15° are punched in columns 13 - 28. Case number in columns 3 - 5 is 81 and column 12 contains the number of elements to be run - six. The 1 in column 79 indicates that incident heats as well as absorbed heats will be printed.

Example D is for use with a trajectory tape mission, since there is no increment $\Delta\phi$ in columns 21 - 28. The case number is 82 and the number of elements is 8. The number 36 in columns 29 - 36 indicates that when a time greater than or equal to 36 min. is read from the trajectory tape, the program will return to the input routine to read changes in some of the case parameters. The Apollo configuration number 3 is punched in column 78. The 1 punch in column 80 causes heat fluxes to be multiplied by element area to give total heats for each element.

A	1 0
B	1 0 SOLAR CONSTANT HAS BEEN CHANGED TO 400 FOR ALL SUCCEEDING CASES
C	0 1 8 1 6 45. 15. 10
D	0 1 8 2 8 36. 301
E	0 2 1. 0. 60. 90. 6.
F	0 2 60225 -1. 0. 0. 60. 1.5
G	0 2 -2 1. 0. -1.73205
H	0 3 1
I	0 3 2 1
J	0 3 80.40E6 3441. 0.58 1.41E14 300.
K	0 4 1180. 225. 170.
L	0 4 1207
M	0 5 1 33.0 0. 0. 1961. 1. 1. 0. 0.
N	0 5 2 280.6997180.60712
O	0 5 3 79.4454480.60712165.7986
P	0 5 5 33.0 0. 0. 281.48 -23.0243
Q	0 6 1 8 03 0. 1. 10000. .96 150000. .93 200000. .89 2
R	0 6 2 4 03 1. 6000. .95 1
S	0 6 1 6 04 0. .6 6000. .8 18000. .82 1
T	0 6 1 8 05 1. 0.95 0.9 0.85 0.8 0.7 0.6 0.5 2
U	0 6 9 10 05 0.3 0. 2
V	0 6 1 8 06 0. 0.2 200. 0.25 400. 0.33 600. 0.45 5
W	0 6 9 14 06 700. 0.5 750. 0.65 10000. 0.65 5
X	0 6 1 2 07
Y	0 6 4 1 08
Z	0 6 4 3 09
AA	0 6 [illegible]
BB	0 6 5 9 11 0.3 0.4 0.5 0.6 0.7
CC	0 7 30. 585.
DD	0 7
EE	0 9 1 40 6 40 6. 1410
FF	0 9 2 56 2 21.5 562. 1.0 1401
GG	0 9 3 563 1563 21.66 1.0 1401
HH	0 9 4 955 45. 60. 1. 0200
II	0 8 21.
JJ	0 8

Fig. 1 - Sample Input Data Cards

C. Orientation and Rotation (02 Card)

Example E contains a 1 in columns 9 - 12 hence the vehicle is planet-oriented. Roll, pitch and yaw angles are 0°, 60° and 90°, respectively. A rotational rate of 6 revolutions per hour is given in columns 37 - 44; therefore, the axis of rotation must also be specified on the card. Since columns 3 - 8 are blank, Ω_r and Λ_r are taken to be zero.

Example F contains -1 in columns 9 - 12, indicating that the vehicle is sun-oriented. Roll, pitch and yaw angles are 0°, 0° and 60°, respectively, and rotational rate is 1.5 revolutions per hour. The axis of rotation is given by $\Omega_r = 60°$, $\Lambda_r = 225°$ read from columns 3 - 8.

Example G is a star-oriented case, as indicated by the -2 in columns 9 - 12. There is no roll, pitch, yaw or rotation.* The star-vector used for orientation has the coordinates 1, 0, - 1.73205. This defines a vector in the X-Z plane which is inclined at 60° to the positive X-axis and 150° to the positive Z-axis. Note that the coordinate system used to define the star vector must be the planet system for orbital missions and the earth equatorial system for trajectory tape missions. Hence, this card has different significance when used with different 04 cards.

D. Planet (03 Card)

Example H contains the planet code for earth (1) in column 5. In the absence of any other data on the card, the program will assume that the planet temperature is constant and will take planet data from internal tables.

Example I contains the planet code for moon (2) in column 5 and a (1) in column 8, indicating planet temperature is variable. Other planet data are taken from tables.

Example J does not contain a valid planet code in column 5, hence it describes an "unknown" planet. In this case, the numbers in the five fields from columns 13 - 52 describe a planet having distance from the sun of 80,400,000 nautical miles, radius of 3,441 nautical miles, albedo of 0.58, GM_p of 141 x 10^{14} ft^2/sec^3 and adjusted cold side temperature of 200°R. This actually describes earth except that the albedo has been changed from 0.35 to 0.58.

E. Mission (04 Card)

Example K contains a 1 punch in column 5, which indicates an orbital mission. The case will compute heats over 180 angular degrees of the orbit

* Blanks indicates Zero (0) values for roll, pitch, and yaw.

(columns 6 - 8). Apogee and perigee are punched as 225 and 170 nautical miles, respectively. Actually, these numbers could have been interchanged since the program takes the larger number as apogee and the smaller as perigee regardless of the field in which they are punched.

Example L describes a trajectory tape mission as indicated by the blank in column 5. The planet codes for earth and moon in columns 9 and 10 mean that the data read from the trajectory tape refers to earth and/or the moon. The 07 punches in columns 11 - 12 have no significance. If a new trajectory tape format were used requiring a tape search to find the desired trajectory, this number could be used as a trajectory identification number.

F. Sun Position (05 Card)

Examples M, N, O and P all describe the same sun position. In example M, the 1 punch in column 5 indicates that the program will use the date and time specified to calculate the solar position. The angles i , ω , and Ω are punched as 33°, 0° and 0°, respectively. The date is 1961, January 1, and the time is 0:00 hr.

Example N gives the angles $\sum$ and β directly as 280.6997° and 80.60712°. Example O gives α, β, and γ of 79.44544°, 80.60712° and 165.7986°. Example P gives the angles i , ω , and Ω as in example M, but columns 37 - 44 contain right ascension and columns 45 - 52 contain declination. The code in column 5 tells the program how the 05 cards are to be interpreted.

G. Redefinition (06 Card)

Example Q has 03 in columns 11 - 12, hence the data on the card will go into a table of f_s vs. t . The 2 punch in column 78 indicates that the second table of f_s vs. t is referenced. The 1 and 8 in columns 3 - 8 indicate that the first eight values of table 2 are to be stored from this card. The eight numbers in columns 13 - 76 provide the following table entries:

t (min.)	f_s
0	1.
10,000	0.96
50,000	0.93
200,000	0.89

Similarly, example R defines the second thru the fourth numbers from table 1 of f_s vs. t .

t (min.)	f_s
(previous value used)	1.
6,000	0.95

Example S defines three entries in table 1 of f_p vs. t as follows:

t (min.)	f_p
0	0.6
6,000	0.8
18,000	0.82

Examples T and U taken together define table 2 (see column 78) of g vs. δ as indicated by the code 05 in columns 11 - 12. Indices in columns 3 - 5 and 6 - 8 indicate that the first eight entries are given on card T and the ninth and tenth on card U. The table defined is:

δ (understood) (°)	g
0	1.0
10	0.95
20	0.9
30	0.85
40	0.8
50	0.7
60	0.6
70	0.5
80	0.3
90	0.0

Examples V and W together define table 5 (see column 78) of b_m vs. T , as indicated by the code 06 in columns 11 - 12. Each table entry requires two numbers. The first eight numbers are on card V and six more are on card W. The end of the table is indicated by an entry for T = 10,000°R in columns 45 - 60 of card W. The table defined by cards V and W follows:

T (°R)	b_m
0	0.2
200	0.25
400	0.33
600	0.45
700	0.5
750	0.65
10,000	0.65

Examples X, Y and Z show cross references of different types. The type of cross reference is coded in columns 11 - 12. The coating material number is in columns 4 - 5. These three cards establish that coating material number 1 has absorptivity for planet radiation which varies with time according to the second table of f_p vs. t, and that coating material number 4 has absorptivity for solar radiation which varies with time according to the first table of f_s vs. t and with angle δ according to the third table of g vs. δ.

If in a subsequent case, the user should want to delete the dependence on time or angle δ from the absorptivity of any material, a card deleting the cross reference may be used. For example, absorptivity of solar radiation for coating material number 4 could be made independent of time by using a card identical to card Y except that column 8 would contain a zero (0) or a blank. This card would destroy the cross reference to table 1 of f_s vs. t.

Example AA redefines the solar constant to be 400. It is advisable to use a comment to call attention to changes of this sort.(see example B).

Example BB contains 11 in columns 11 - 12, which is the code indicating that the card defines values of a_m. The 5 and 9 punches in columns 5 and 8 indicate that coating materials 5 - 9 are referenced. Values of a_5 through a_9 are 0.3, 0.4, 0.5, 0.6 and 0.7, respectively.

H. Low Altitude Planet Temperature (07 Card)

Example CC defines planet temperature to be 585°R when the vehicle is at an altitude less than 30 nautical miles.

Example DD might be used on a case subsequent to example CC to cancel the former card. Since critical altitude is zero (blank) the program will ignore this low altitude logic for all (positive) altitudes. If the

DD card were not used, the program would continue to set planet temperature to 585°R whenever altitude dropped below 30 n.m. Low altitude logic is always suppressed until the program reads an 07 card.

I. Element (09 Card)

Since a case may have more than one element and since the interrelation of elements concerns data card preparation, examples EE, FF, GG and HH are discussed together.

First, they are given sequence numbers 1, 2, 3 and 4 in column 5. The first three of these have valid node numbers in columns 6 - 8, hence, they normally will be assigned area, Λ_n and Ω_n, from internal tables. Since the first two of these have no label in columns 9 - 12, they will be given labels to agree with their node numbers. These labels agree with the numbers punched in columns 37 - 44 of the respective cards. Therefore, each of these elements will be lumped with the element following it. This group terminates with the third card, GG, which is not to be lumped with the one following since the label (1563) is not reproduced in columns 37 - 44. Hence, the third element is the last of the group and its label will be used in printing out results for the group of three.

In example HH, no node number is punched in columns 6 - 8 and therefore Λ_n, Ω_n and area must take on the values 45°, 60° and 1 ft.^{2} from columns 13 - 36. This element is assigned a label of 955 from columns 9 - 12.

Elements which are defined by a node number in columns 6 - 8 normally take Λ_n, Ω_n and area from internal tables. However, examples FF and GG show an exception to this, for the areas are stored as 2.5 ft.^{2} and 2.66 ft.^{2}. from columns 29 - 36. The numbers 1.0 in columns 61 - 66 are necessary to make the program recognize the quantities in columns 29 - 36.

The coating material codes in columns 77 - 78 are the fourteenth for the first three elements and the second for the fourth. Codes punched in column 79 will cause shadow logic to be used only on the first element; i.e., the first of the three which are lumped together. Punches in column 80 show that plots are requested for the second and third elements. However, the plot request for the second element will be ignored since it is lumped with the third element. The plot which is generated for element 3 will be a sum of the three elements. If column 80 of GG had contained zero or blank, the plot would have been suppressed even though FF contained a signal to plot. This illustrates the point that plot control for a group of elements which are lumped together must appear on the last element card of the group, that is, the one having the highest sequence number in columns 3 - 5.

J. Trajectory Continuation (08 Card)

Examples II and JJ show two trajectory continuation cards that might be used in conjunction with example D, which will cause the program to return for more input when a time greater than or equal to 36 min. is read from the trajectory tape. Example II would be placed in the deck immediately following the cards which define case parameters at the beginning of the mission. Data cards defining changes which are to take place at 36 min. should follow and they are terminated by card JJ. The number 71 in columns 13 - 20 of card II indicates that the case parameters will be changed again when a trajectory time of 71 min. is reached. After card JJ, additional data cards would be placed to define case parameters beyond 71 min. These changes would be followed by a blank card. Since card JJ does not contain a number in columns 13 - 20, the last set of data read will be used to compute until the end of the trajectory. If computations for times beyond 71 min. were not desired, card JJ could have been replaced by a blank which would have terminated the case at 71 min.

V. PROGRAM OUTPUT

The program has two types of output - printed output, which is always generated, and plotted output, which can be obtained as an option for each surface element.

A. Printed Output

The printed output format is illustrated in Fig. 2. At the beginning of the output of each case, the case number is printed followed by the comments for the case. After the comments, information identifying planet, orientation, orbit, sun position and vehicle roll, pitch and yaw are printed. These items are all clearly labeled. Finally, a list of element data is printed. For each element used in the case, the sequence number is printed followed by the node number, the angles Ω_n and Λ_n giving the orientation of the element with respect to the body coordinate system, the area in square feet, and the coating material number. All angles are given in degrees.

The element list concludes the output describing the case being run. It is followed by one or more pages of heat flux tabulations. At the head of each page of heat fluxes is a line of alphameric output which is taken from the first comment card for the case if an orbital mission is being run or from the identification record on tape, if the mission is defined by trajectory tape.

CASE NUMBER 211
TEST OF PROGRAM OPTION TO CONTROL PLANET TEMPERATURE AT LOW ALTITUDES
EARTH TEMPERATURE IS SET TO 1000 DEGREES RANKINE BELOW 110 N.M.

PLANET EARTH SATELLITE IS PLANET ORIENTED PLANET TEMPERATURE IS CONSTANT

APOGEE	PERIGEE	PHIO	DPHI	SIGMA	BETA	PHIN	PHOUT
100.00000	100.00000	0.	30.00000	30.00000	90.00000	133.65602	286.34396

ALPHA= 30.00 GAMMA= 60.00

ROLL= 0. PITCH= 0. YAW= 300.00
NO ROTATION

SEQ.	NODE	LAMBDA	OMEGA	AREA	COATING
1	1	120.000	45.000	1.00000	1
2	2	0.	90.000	1.00000	1
3	3	165.000	90.000	1.00000	1

TEST OF PROGRAM OPTION TO CONTROL PLANET TEMPERATURE AT LOW ALTITUDES

			---INCIDENT HEAT FLUXES--			-------ABSORBED HEAT FLUXES-------				ABSORPTIVITIES			SHADOWS	
TIME (MIN.)	PHI (DEG.)	NODE	QISUN B/HR-SQF	QIALB B/HR-SQF	QIPLN B/HR-SQF	QASUN B/HR-SQF	QAALB B/HR-SQF	QAPLN B/HR-SQF	QATOT B/HR-SQF	SUN	ALB	PLN	SUN	PLN
0.	0.	1	271.28	11.18	128.09	81.38	3.36	115.28	200.02	0.300	0.300	0.900	1.0	1.0
		2	0.	88.17	1028.99	0.	26.45	926.09	952.54	0.300	0.300	0.900	1.0	1.0
		3	427.91	11.62	128.09	128.37	3.49	115.28	247.14	0.300	0.300	0.900	1.0	1.0
7.33	30.00	1	313.25	12.91	128.09	93.97	3.87	115.28	213.13	0.300	0.300	0.900	1.0	1.0
		2	0.	103.72	1028.99	0.	31.12	926.09	957.20	0.300	0.300	0.900	1.0	1.0
		3	313.25	12.91	128.09	93.97	3.87	115.28	213.13	0.300	0.300	0.900	1.0	1.0
14.66	60.00	1	271.28	11.18	128.09	81.38	3.36	115.28	200.02	0.300	0.300	0.900	1.0	1.0
		2	0.	91.49	1028.99	0.	27.45	926.09	953.54	0.300	0.300	0.900	1.0	1.0
		3	114.66	10.73	128.09	34.40	3.22	115.28	152.89	0.300	0.300	0.900	1.0	1.0
21.99	90.00	1	156.62	6.45	128.09	46.99	1.94	115.28	164.20	0.300	0.300	0.900	1.0	1.0
		2	221.50	54.73	1028.99	66.45	16.42	926.09	1008.96	0.300	0.300	0.900	1.0	1.0
		3	0.	5.67	128.09	0.	1.70	115.28	116.98	0.300	0.300	0.900	1.0	1.0
29.32	120.00	1	0.00	0.23	128.09	0.00	0.07	115.28	115.35	0.300	0.300	0.900	1.0	1.0
		2	383.65	3.39	1028.99	115.09	1.02	926.09	1042.20	0.300	0.300	0.900	1.0	1.0
		3	0.	0.04	128.09	0.	0.01	115.28	115.29	0.300	0.300	0.900	1.0	1.0
33.66	133.66	1	0.	0.	128.09	0.	0.	115.28	115.28	0.300	0.300	0.900	1.0	1.0
		2	425.10	0.	1028.99	127.53	0.	926.09	1053.62	0.300	0.300	0.900	1.0	1.0
		3	0.	0.	128.09	0.	0.	115.28	115.28	0.300	0.300	0.900	1.0	1.0
36.65	150.00	1	0.	0.	128.09	0.	0.	115.28	115.28	0.300	0.300	0.900	1.0	1.0
		2	0.	0.	1028.99	0.	0.	926.09	926.09	0.300	0.300	0.900	1.0	1.0
		3	0.	0.	128.09	0.	0.	115.28	115.28	0.300	0.300	0.900	1.0	1.0

Fig. 2 - Typical Printed Output

[illegible] is also printed which gives labels and units for each [illegible] the tabulation. The first two columns are labeled TIME [illegible] is in minutes and true anomaly, ϕ , is in degrees. If [illegible] is being run, time and ϕ are printed only for the [illegible] tape missions, a value of 180° is printed for ϕ , [illegible] has no real significance. The element labels (or node [illegible] in the third column. If program control parameters [illegible] require that incident heats be printed, these come next. [illegible] after incident heats or after element labels if incident [illegible] Following absorbed heats are absorptivities for solar, [illegible], and last come shadow factors for sun and planet [illegible] factors of 0. and 1. indicate completely shadowed and [illegible] cases, respectively.

[illegible] more elements are lumped together only one line of output [illegible] combination. In this case, heats printed are the sums of [illegible] the individual elements. The absorptivities and shadow [illegible] refer only to the last of the elements which are lumped

[illegible] which are lumped together, the heats represent the [illegible] the component parts. When the program option to print [illegible] total heats is used, the sum of heat fluxes for two or [illegible] be meaningful.

[illegible]

[illegible] plotted output is shown in Fig. 3. If plots are required [illegible] run in a case, the program will generate one general [illegible] which gives the user's description of the case to follow. [illegible] may be used for this description. These will normally [illegible] read for the case (on cards with card code 10). [illegible] tape missions the first comment is replaced by the [illegible] from the trajectory tape. Hence, if the user wishes to [illegible] for trajectory tape cases, he should place a card [illegible] except ten (10) in columns 1 and 2 ahead of the first [illegible] "comment" will then be replaced by the trajectory iden- [illegible] own comments will be retained.

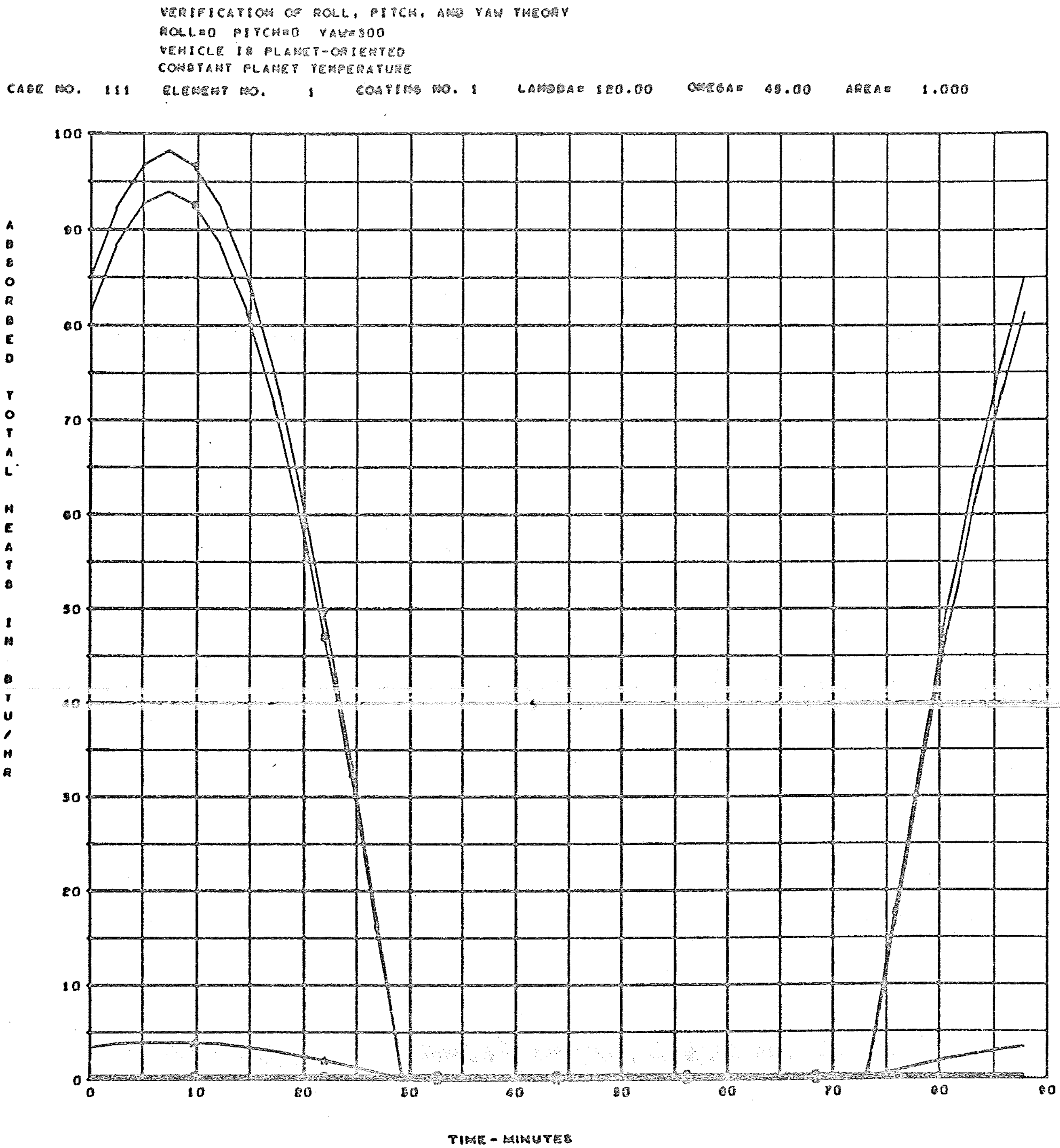


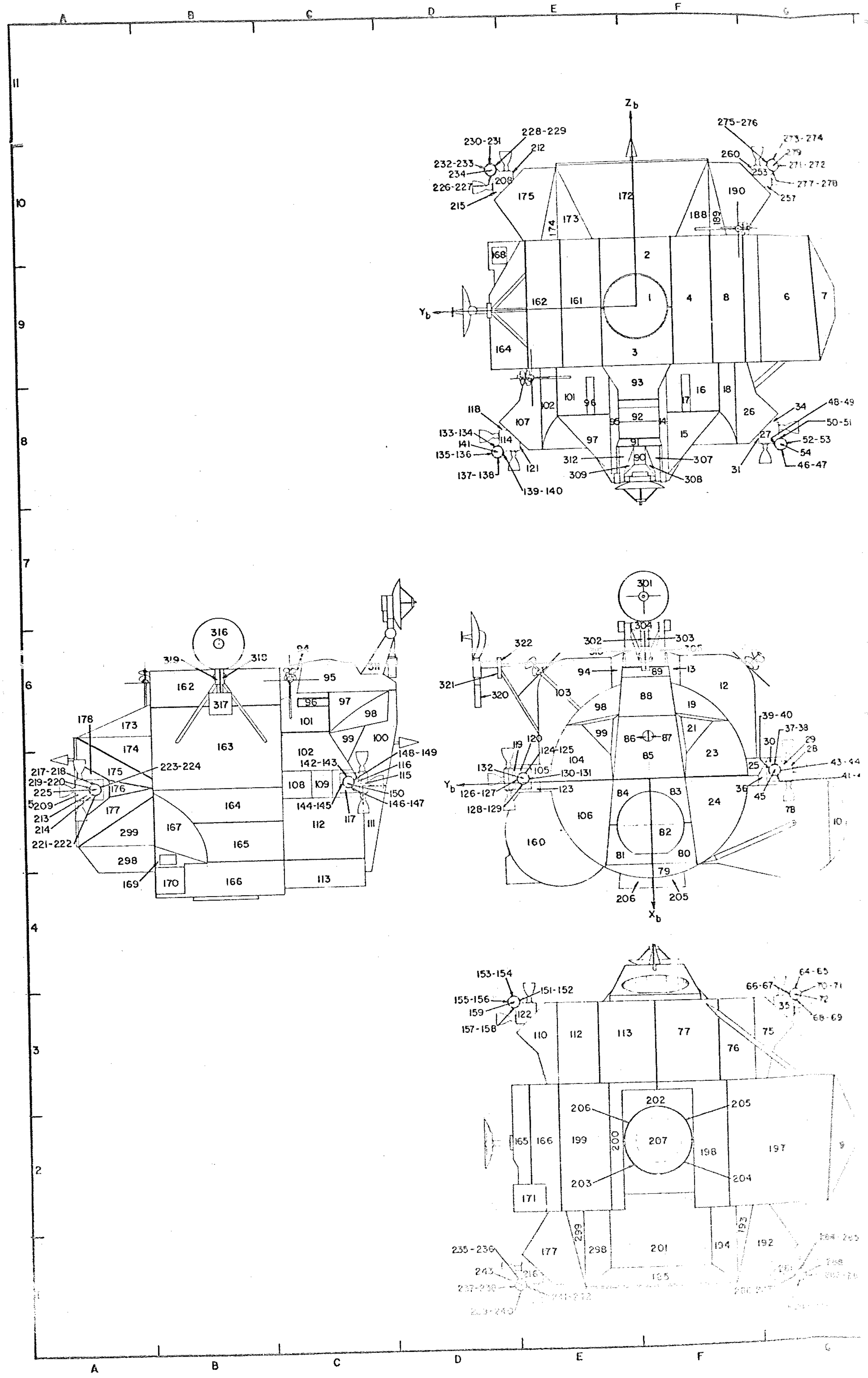
Fig. 3 - Typical Plotted Output

Following the general identification frame are additional frames - each containing graphs of heat loads for one of the elements requiring plots. The first four lines of general comments are repeated at the top, along with the case number and data describing the element. Four curves are drawn on the grid representing solar, albedo, planet and total heats. There are labeled with the letters S, A, P and T, respectively.

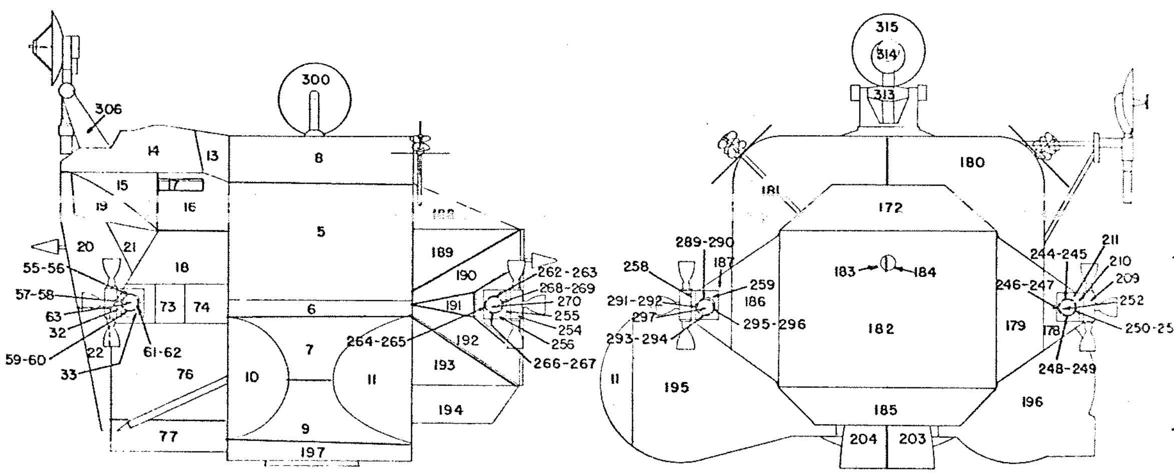
For elements which are lumped together the heats represent the sum of the heats for the component parts. When the program option to print fluxes rather than total heats is used, the sum of heat fluxes for two or more elements may not be meaningful.

APPENDIX A

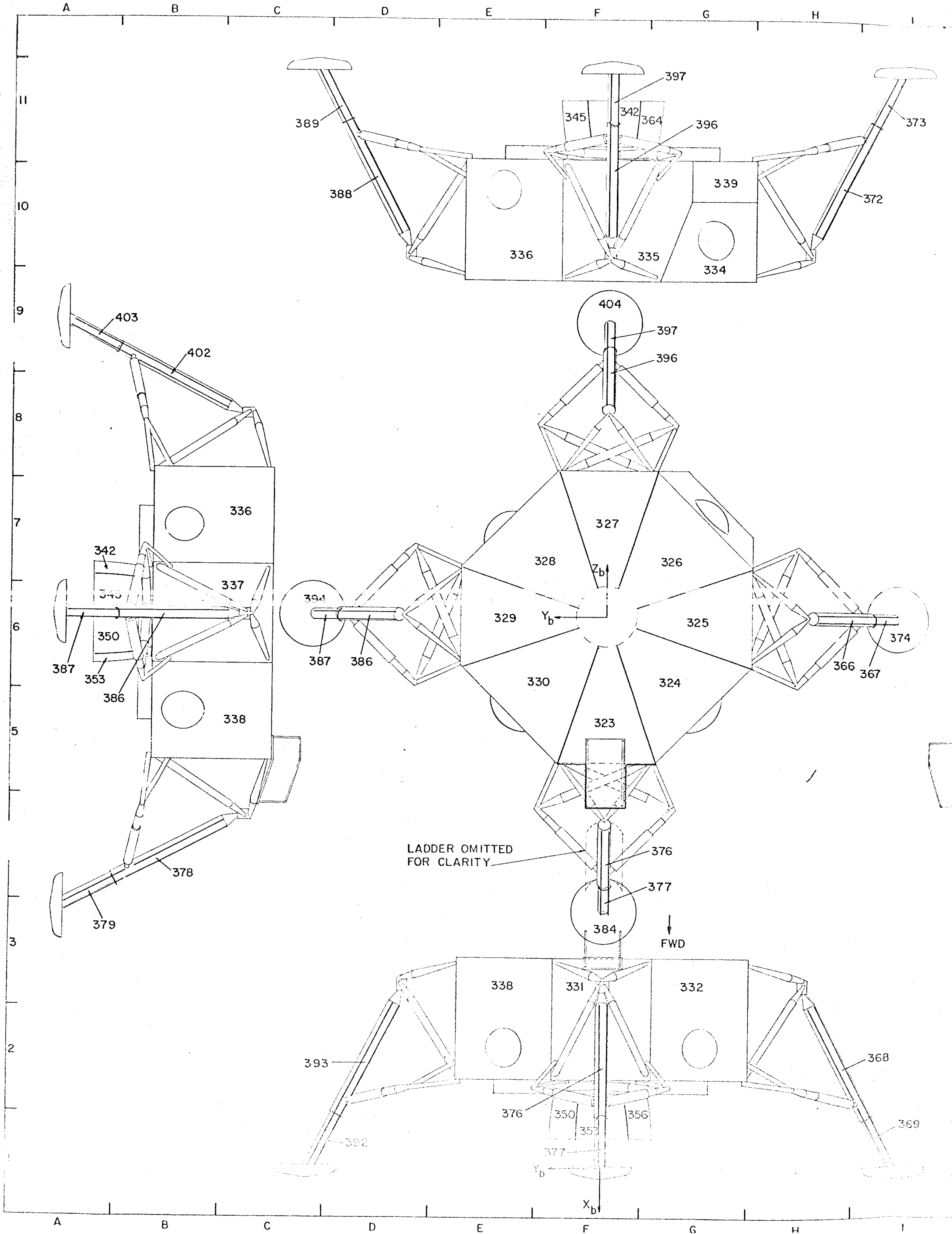
NODE LOCATIONS



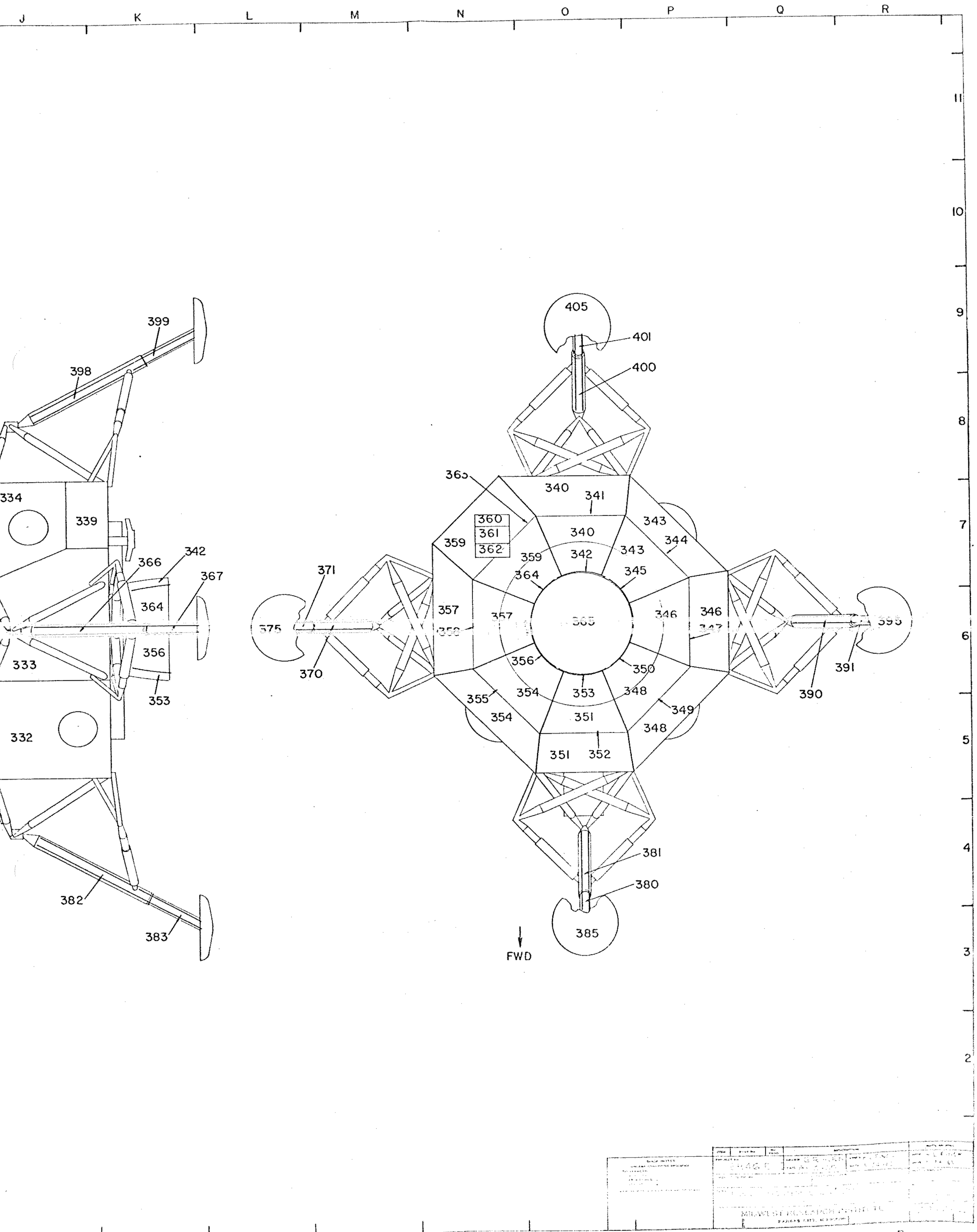
A B C D E F G
11
10
9
8
7
6
4
3
2
Z_b
Y_b
X_b
230-231
228-229
232-233
234
212
226-227
208
215
175
172
173
174
188
189
190
275-276
273-274
260
279
253
271-272
277-278
257
168
2
162
161
1
4
8
6
7
164
3
93
101
96
17
16
18
102
92
107
26
118
95
94
97
91
15
34
48-49
50-51
133-134
114
141
135-136
121
312
90
307
27
52-53
54
46-47
31
137-138
309
308
139-140
316
319
318
311
162
95
96
97
98
317
101
173
178
174
163
99
100
102
223-224
142-143
148-149
116
115
217-218
175
219-220
225
176
108
109
150
146-147
144-145
209
177
164
112
117
111
213
214
299
167
165
221-222
298
169
170
166
113
301
304
302
303
322
94
89
13
321
320
103
88
12
98
19
39-40
37-38
30
29
28
99
86
87
21
23
119
120
124-125
104
85
132
105
130-131
25
43-44
123
84
83
24
36
45
126-127
128-129
106
78
82
160
81
80
79
206
205
153-154
151-152
64-65
66-67
155-156
159
122
35
72
68-69
157-158
110
112
113
77
76
75
202
206
205
165
166
199
200
207
198
197
203
204
171
299
193
235-236
177
298
201
104
192
243
216
135



NOTE:
NOZZLE NUMBERS INDICATED, READ IN PAIRS,
THE FIRST NO. INDICATES STEM OF NOZZLE,
THE SECOND NO. INDICATES BELL OF NOZZLE.



A
B
C
D
E
F
G
H
I
11
10
9
8
7
6
5
3
2
397
389
345
342
364
396
373
388
339
372
336
335
334
404
403
402
336
327
328
326
342
337
Zb
394
Yb
329
325
350
374
387
353
387
386
366
367
386
330
324
338
323
LADDER OMITTED
FOR CLARITY
376
378
377
379
384
FWD
338
331
332
393
368
376
350
353
356
369
392
377
Yb
Xb



399
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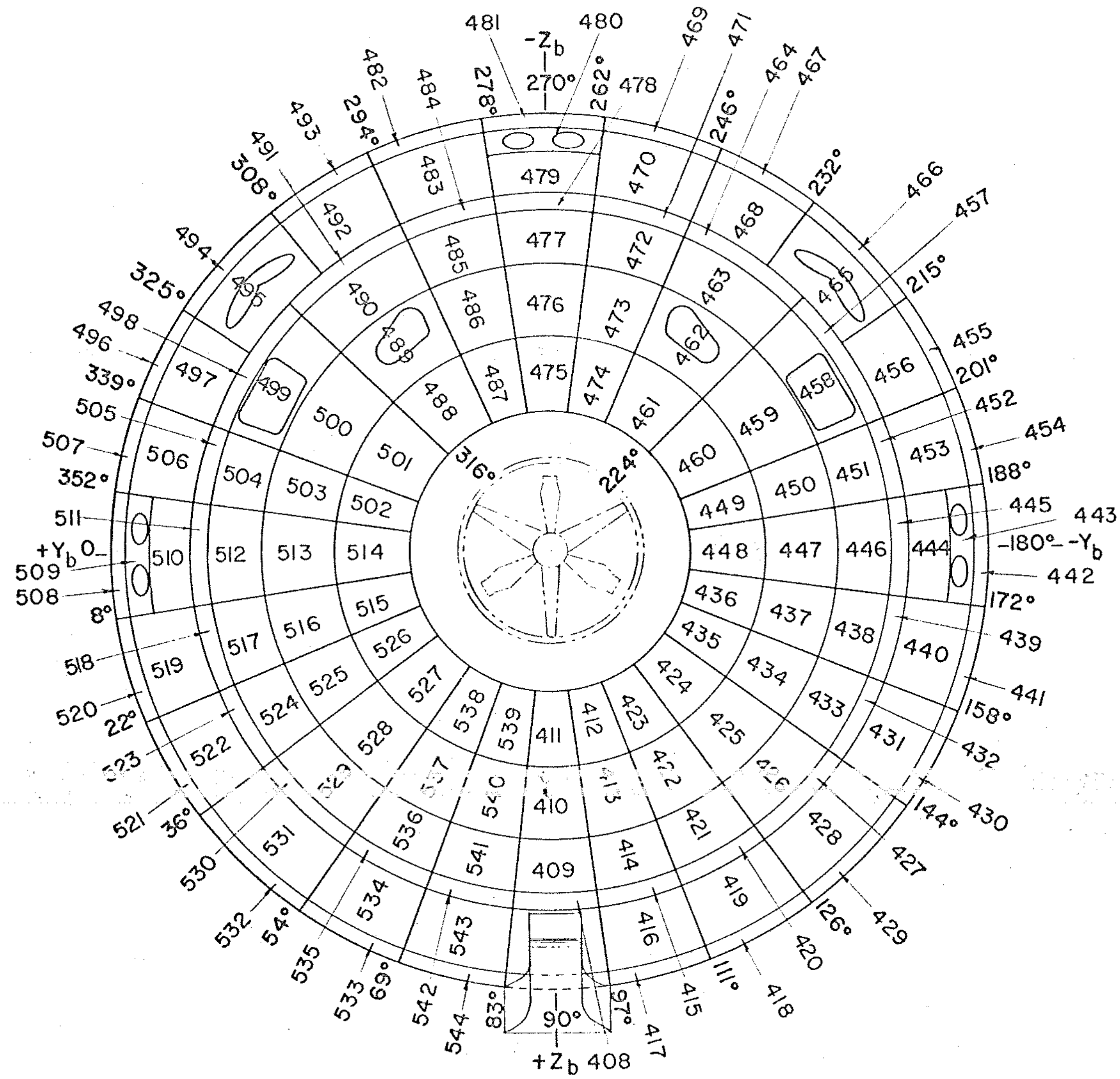
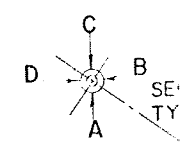
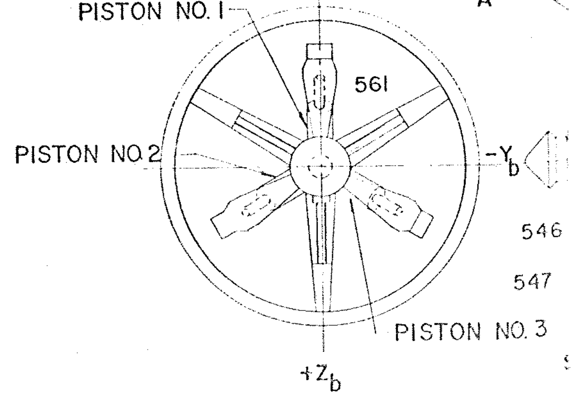
385
FWD

A B C D E F

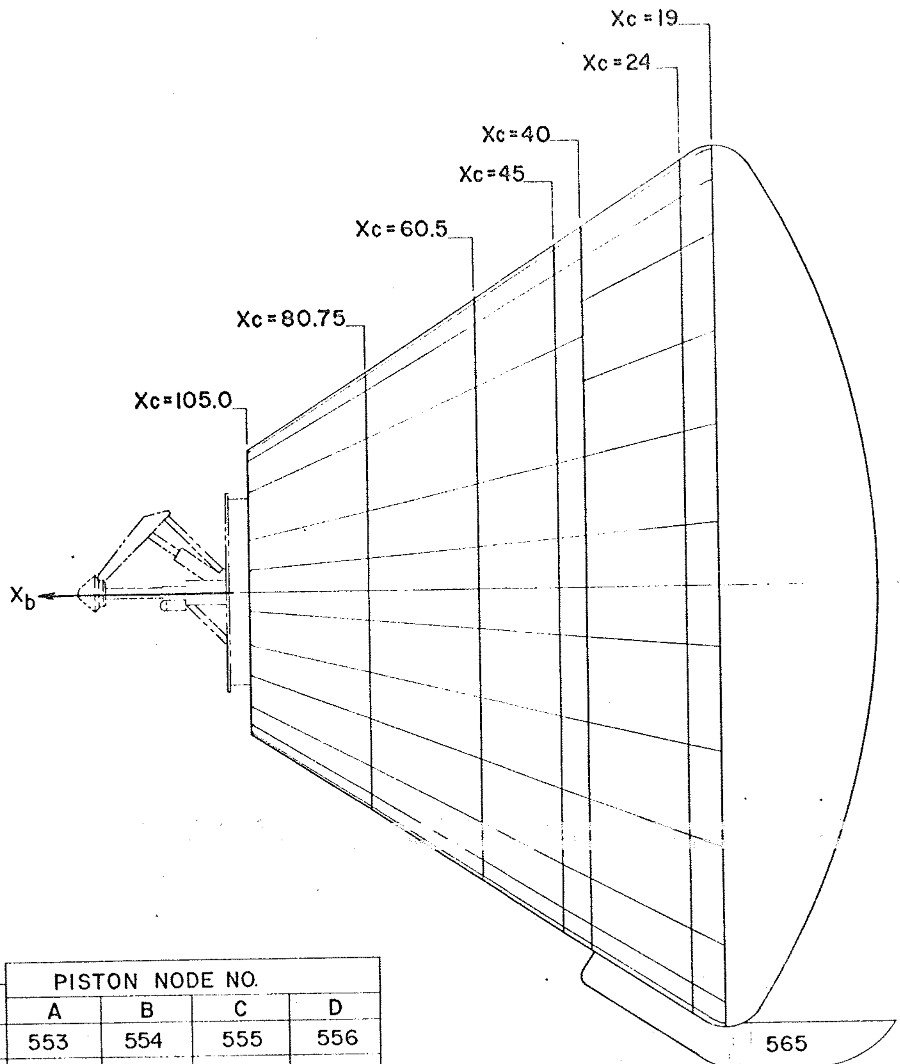




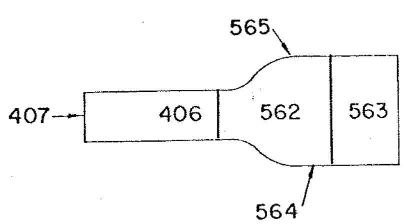


DOCKING PROBE

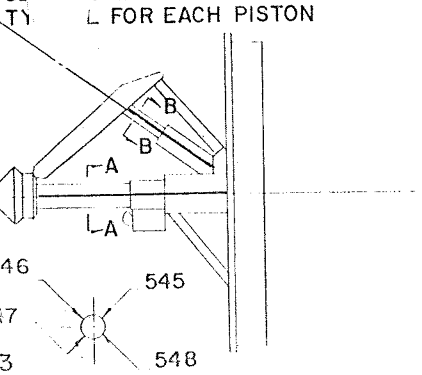
A B C D E



PISTON NO.	PISTON NODE NO. A	B	C	D
1	553	554	555	556
2	557	558	560	559
3	549	550	551	552



SE N B-B
TY L FOR EACH PISTON



SECTION A-A

SHOP NOTES
UNLESS OTHERWISE SPECIFIED
TOLERANCES:
ANGULAR
FRACTIONAL
DECIMAL
REMOVE BURRS AND BREAK SHARP EDGES

ITEM	PART No.	No. REQD.	DESCRIPTION	MAT'L OR SPEC.
PROJECT No. 2846E			DRAWN G.R. HORN DATE 8-20-65 / CHK'D H.L. FINCH DATE 8-23-65	APPR. H.L. FINCH DATE 8-23-65
PROTECTIVE FINISH			HEAT TREAT FOR	NEXT ASSEMBLY
TITLE NODE LOCATIONS - COMMAND MODULE				SCALE NONE

MIDWEST RESEARCH INSTITUTE
KANSAS CITY, MISSOURI

℄ REACTION CONTROL SYSTEM 320.9

QUAD #3 7°15' — ℄ REACTION CONTROL SYSTEM (TYPICAL)

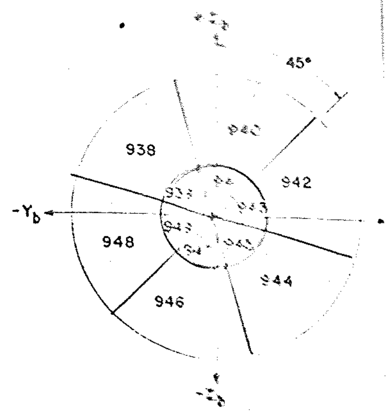
921	920	919	918	917	916	915	914	
								270° $-Z_b$
906	907	908	909	910	911	912	913	
905	904	903	902	901	900	899	898	
								240°
890	891	892	893	894	895	896	897	
889	888	887	886	885	884	883	882	
								210°
874	875	876	877	878	879	880	881	
873	872	871	870	869	868	867	866	
								180 $-Y_b$
858	859	860	861	862	863	864	865	
857	856	855	854	853	852	851	850	
								150°
842	843	844	845	846	847	848	849	
841	840	839	838	837	836	835	834	
								120°
826	827	828	829	830	831	832	833	
825	824	823	822	821	820	819	818	
								90° $+Z_b$
810	811	812	813	814	815	816	817	
809	808	807	806	805	804	803	802	
								60°
794	795	796	797	798	799	800	801	
793	792	791	790	789	788	787	786	
								30°
778	779	780	781	782	783	784	785	
777	776	775	774	773	772	771	770	
								360° $+Y_b$
762	763	764	765	766	767	768	769	
761	760	759	758	757	756	755	754	
								330°
746	747	748	749	750	751	752	753	
745	744	743	742	741	740	739	738	
								300°
730	731	732	733	734	735	736	737	

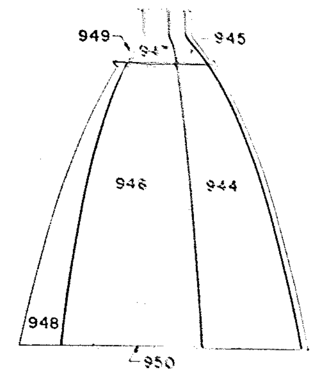
#4 7°15' (at rows 873/858); #1 7°15' (at rows 825/810); #2 7°15 (at rows 777/762)

Xs=381 Xs=355 Xs=332 Xs=310 Xs=288 Xs=266 Xs=244 Xs=222 Xs=200

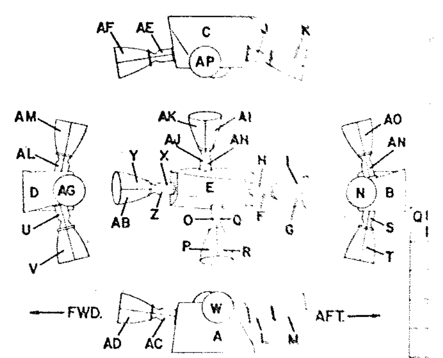
FWD ← → AFT

SURFACE AREA OF SERVICE MODULE

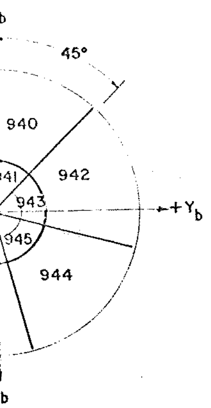


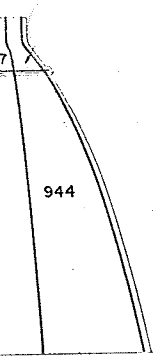


THRUST NOZZLE

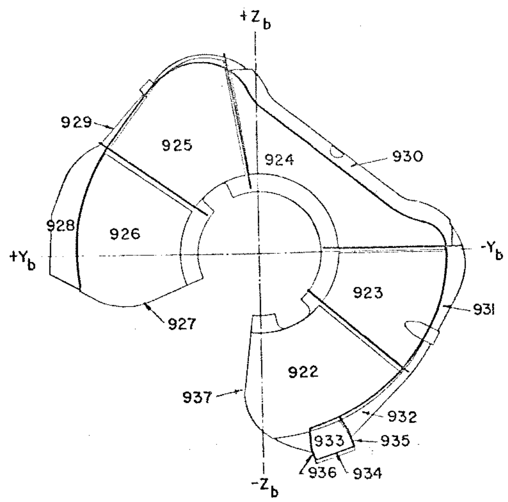


TYPICAL REACTION CONTROL SYSTEM QUAD
SEE TABLE FOR NODAL DISTRIBUTION

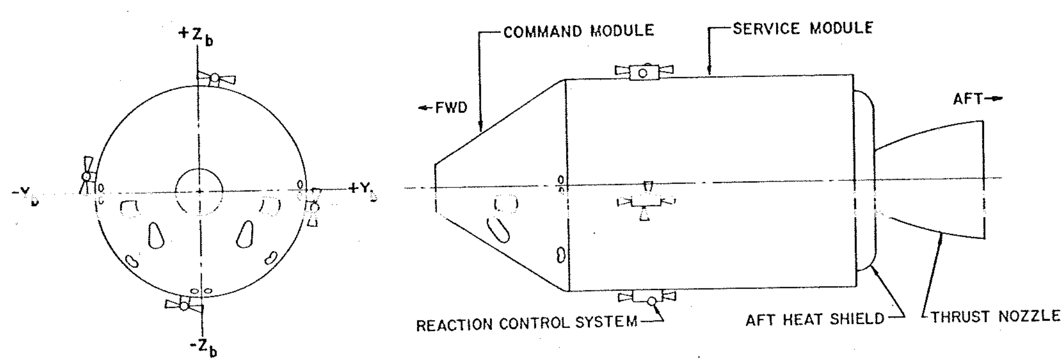




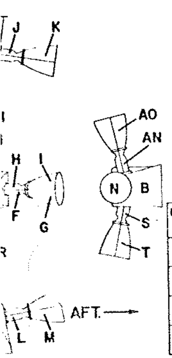
T NOZZLE



AFT HEAT SHIELD



ORIENTATION DETAIL



TROL SYSTEM QUAD
AL DISTRIBUTION

REACTION CONTROL ENGINE NODAL DISTRIBUTION

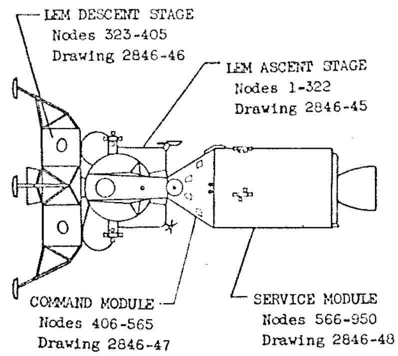
QUAD NO.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586
2	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627
3	648	649	650	651	652	671	672	673	674	675	676	677	678	679	662	663	664	665	666	667	668
4	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709

QUAD NO.	V	W	X	Y	Z	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
1	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606
2	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647
3	669	670	653	654	655	656	657	658	659	660	661	680	681	682	683	684	685	686	687	688
4	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729

APPENDIX B

NODE DATA

GEOMETRIC DATA



1-322 ARE LOCATED ON THE LEM ASCENT STAGE (DRAWING 2846-45)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Location of Surface Element Λ_n (degrees)	Node Location Drawing Number	Node Location Location Code	Notes
1	5.59	90.0	180.0	2846-45	F-9	1. Area is 0.0 for Configurations 2,5.
2	5.16	90.0	180.0	45	F-9	2. Area is 3.23 for Configurations 2,5.
3	5.16	90.0	180.0	45	F-9	3. Area is 3.23 for Configurations 2,5.
4	9.10	90.0	180.0	45	F-9	
5	18.47	90.0	270.0	45	J-6	
6	14.35	90.0	178.5	45	G-9,J-5	
7	6.56	90.0	240.75	45	G-9,J-5	
8	10.90	90.0	225.0	45	F-9,J-6	
9	6.56	90.0	299.25	45	G-2,J-4	
10	4.34	113.42	270.0	45	G-5,I-5	
11	4.51	67.0	270.0	45	J-5,K-5	
12	7.47	180.0	undefined	45	F-6	
13	1.35	117.17	270.0	45	F-6,I-6	
14	3.82	90.0	263.5	45	F-8,I-6	
15	3.65	90.0	208.50	45	F-8,I-6	
16	5.40	90.0	215.33	45	F-8,I-6	
17	0.68	90.0	202.83	45	F-8,I-6	
18	4.69	90.0	248.75	45	F-8,I-5	
19	1.95	134.25	270.0	45	F-6,H-6	
20	3.87	92.0	263.5	45	H-6	
21	1.90	142.0	300.0	45	F-6,I-6	
22	1.99	92.0	263.5	45	H-5	
23	4.90	149.50	180.0	45	F-5	
24	6.58	180.0	undefined	45	F-5	
25	0.42	149.50	180.0	45	G-5	
26	3.36	90.0	180.0	45	G-8	
27	0.69	90.0	180.0	45	G-8	
28	0.51	135.0	270.0	45	G-5	
29	0.20	135.0	90.0	45	G-5	
30	0.50	180.0	undefined	45	G-5	
31	0.32	90.0	90.0	45	F-8	
32	0.20	45.0	270.0	45	H-5	
33	0.50	90.0	270.0	45	H-5	
34	0.32	0	undefined	45	G-8	
35	0.69	90.0	0	45	G-3	
36	0.97	135.0	270.0	45	F-5	
37	0.0436	90.0	180.0	45	G-6	
38	0.139	76.0	180.0	45	G-6	
39	0.0436	90.0	90.0	45	G-6	
40	0.139	76.0	90.0	45	G-6	
41	0.0436	90.0	0	45	G-5	
42	0.139	76.0	0	45	G-5	
43	0.0436	90.0	270.0	45	G-5	
44	0.139	76.0	270.0	45	G-5	
45	0.165	180.0	undefined	45	G-5	
46	0.0436	180.0	undefined	45	G-8	
47	0.139	166.0	0	45	G-8	
48	0.0436	90.0	90.0	45	G-8	
49	0.139	90.0	76.0	45	G-8	
50	0.0436	0	undefined	45	G-8	
51	0.139	14.0	0	45	G-8	
52	0.0436	90.0	270.0	45	G-8	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale ($ft.^2$)	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						1-322 ARE LOCATED ON THE LEM ASCENT STAGE (DRAWING 2846-45)
53	0.139	90.0	284.0	2846-45	G-8	
54	0.165	90.0	180.0	45	G-8	
55	0.0436	90.0	180.0	45	H-5	
56	0.139	90.0	166.0	45	H-5	
57	0.0436	180.0	undefined	45	H-5	
58	0.139	166.0	90.0	45	H-5	
59	0.0436	90.0	0	45	H-5	
60	0.139	90.0	14.0	45	H-5	
61	0.0436	0	undefined	45	I-5	
62	0.139	14.0	90.0	45	I-5	
63	0.165	90.0	270.0	45	H-5	
64	0.0436	180.0	undefined	45	G-3	
65	0.139	166.0	180.0	45	G-3	
66	0.0436	90.0	90.0	45	G-3	
67	0.139	90.0	104.0	45	G-3	
68	0.0436	0	undefined	45	G-3	
69	0.139	14.0	180.0	45	G-3	
70	0.0436	90.0	270.0	45	G-3	
71	0.139	90.0	256.0	45	G-3	
72	0.165	90.0	0	45	G-3	
73	1.36	45.0	270.0	45	I-5	
74	1.56	75.0	270.0	45	I-5	
75	3.36	90.0	0	45	G-3	
76	9.72	90.0	299.25	45	F-3,I-5	
77	9.72	90.0	343.0	45	F-3,I-4	
78	16.53	180.0	undefined	45	G-5	
79	1.66	180.0	undefined	45	F-4	
80	1.74	168.92	0	45	F-5	
81	1.74	168.92	0	45	E-5	
82	5.69	180.0	undefined	45	F-5	
83	1.47	168.92	0	45	F-5	
84	1.47	168.92	0	45	E-5	
85	6.94	168.92	0	45	F-5	
86	0.52	105.0	90.0	45	F-5	
87	0.52	105.0	270.0	45	F-5	
88	3.60	180.0	undefined	45	F-6	
89	1.30	124.5	180.0	45	F-6	
90	0.72	90.0	180.0	45	F-8	
91	1.24	154.17	180.0	45	F-8	
92	2.74	107.5	180.0	45	F-8	
93	3.26	73.83	180.0	45	F-8	
94	1.35	117.17	90.0	45	C-6,E-6	
95	3.82	90.0	96.5	45	C-6,E-8	
96	0.68	90.0	157.17	45	C-6,E-8	
97	3.65	90.0	151.50	45	C-6,E-8	
98	1.95	134.25	90.0	45	C-6,E-6	
99	1.90	142.0	60.0	45	C-6,E-6	
100	3.87	92.0	96.5	45	C-6	
101	5.40	90.0	144.67	45	C-6,E-8	
102	4.69	90.0	111.25	45	C-5,E-8	
103	7.47	180.0	undefined	45	E-6	
104	4.90	149.50	180.0	45	E-5	
105	0.42	149.50	180.0	45	E-5	
106	6.58	180.0	undefined	45	E-5	
107	3.36	90.0	180.0	45	E-8	
108	1.56	75.0	90.0	45	C-5	
109	1.36	45.0	90.0	45	C-5	
110	3.36	90.0	0	45	E-3	
111	1.99	92.0	96.5	45	C-5	
112	9.72	90.0	70.75	45	C-5,E-3	
113	9.72	90.0	17.0	45	C-4,E-3	
114	0.69	90.0	180.0	45	E-8	
115	0.51	135.0	90.0	45	D-5	
116	0.20	45.0	90.0	45	D-5	
117	0.50	90.0	90.0	45	C-5	
118	0.32	0	undefined	45	D-8	
119	0.20	135.0	270.0	45	E-5	
120	0.50	180.0	undefined	45	E-6	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	A_n (degrees)	Node Location Drawing Number	Location Code	Notes
						1-322 ARE LOCATED ON THE LEM ASCENT STAGE (DRAWING 2846-45)
121	0.32	90.0	270.0	2846-45	E-8	
122	0.69	90.0	0	45	E-3	
123	0.97	135.0	90.0	45	E-5	
124	0.0436	90.0	180.0	45	E-5	
125	0.139	76.0	180.0	45	E-5	
126	0.0436	90.0	90.0	45	D-5	
127	0.139	76.0	90.0	45	D-5	
128	0.0436	90.0	0	45	D-5	
129	0.139	76.0	0	45	D-5	
130	0.0436	90.0	270.0	45	E-5	
131	0.139	76.0	270.0	45	E-5	
132	0.165	180.0	undefined	45	D-5	
133	0.0436	0	undefined	45	D-8	
134	0.139	14.0	0	45	D-8	
135	0.0436	90.0	90.0	45	D-8	
136	0.139	90.0	76.0	45	D-8	
137	0.0436	180.0	undefined	45	D-8	
138	0.139	166.0	0	45	D-8	
139	0.0436	90.0	270.0	45	E-8	
140	0.139	90.0	284.0	45	E-8	
141	0.165	90.0	180.0	45	D-8	
142	0.0436	90.0	180.0	45	C-5	
143	0.139	90.0	194.0	45	C-5	
144	0.0436	0	undefined	45	C-5	
145	0.139	14.0	270.0	45	C-5	
146	0.0436	90.0	0	45	D-5	
147	0.139	90.0	346.0	45	D-5	
148	0.0436	180.0	undefined	45	D-5	
149	0.139	166.0	270.0	45	D-5	
150	0.165	90.0	90.0	45	D-5	
151	0.0436	90.0	270.0	45	E-3	
152	0.139	90.0	256.0	45	E-3	
153	0.0436	180.0	undefined	45	D-4	
154	0.139	166.0	180.0	45	D-4	
155	0.0436	90.0	90.0	45	D-3	
156	0.139	90.0	104.0	45	D-3	
157	0.0436	0	undefined	45	D-3	
158	0.139	14.0	180.0	45	D-3	
159	0.165	90.0	0	45	D-3	
160	8.02	180.0	undefined	45	E-5	
161	9.10	90.0	180.0	45	E-9	
162	10.90	90.0	135.0	45	B-6,E-9	
163	18.47	90.0	90.0	45	B-6	
164	8.06	90.0	140.0	45	B-5,E-9	
165	6.25	90.0	93.25	45	B-5,E-2	
166	11.63	90.0	28.5	45	B-4,E-2	
167	4.58	58.60	90.0	45	B-5	
168	0.33	90.0	180.0	45	E-10	168 The Surface is Parallel to the Y-Z Plane
169	2.55	90.0	146.42	45	A-4	169 Area is the Triangular Shaped Surface Excluding the Projection of 163
170	1.17	90.0	90.0	45	B-4	
171	1.72	90.0	0	45	E-2	
172	16.91	64.2	180.0	45	F-10,M-6	
173	3.09	90.0	142.6	45	A-6,E-10	
174	2.93	90.0	108.25	45	A-6,E-10	
175	4.94	116.0	154.0	45	A-5,E-10	
176	0.80	123.0	90.0	45	A-5	
177	4.94	116.0	26.0	45	A-5,E-1	
178	2.60	45.0	90.0	45	A-6,N-5	
179	5.00	0	undefined	45	N-5	
180	8.96	0	undefined	45	M-6	
181	8.96	0	undefined	45	L-6	
182	27.41	0	undefined	45	M-5	
183	0.52	75.0	270.0	45	M-5	

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						1-322 ARE LOCATED ON THE LEM ASCENT STAGE (DRAWING 2846-45)
184	0.52	75.0	90.0	2846-45	M-5	
185	7.02	38.0	0	45	F-1,M-5	
186	5.00	0	undefined	45	L-5	
187	2.60	45.0	270.0	45	L-5	
188	3.09	90.0	217.4	45	F-10,J-6	
189	2.93	90.0	251.75	45	F-10,J-6	
190	4.94	116.0	206.0	45	F-10,K-5	
191	0.80	123.0	270.0	45	K-5	
192	4.94	116.0	334.0	45	F-1,K-5	
193	2.89	90.0	287.2	45	F-1,K-5	
194	3.90	90.0	315.0	45	F-1,K-5	
195	16.53	0	undefined	45	L-5	
196	8.44	0	undefined	45	N-5	
197	24.03	90.0	15.0	45	G-2,J-4	
198	8.27	90.0	0	45	F-2	
199	9.86	90.0	335.42	45	E-2	
200	3.54	90.0	0	45	E-2	
201	11.11	90.0	0	45	F-1	
202	6.53	90.0	0	45	F-3	
203	5.73	55.0	108.0	45	E-2,M-4	
204	5.73	55.0	252.0	45	F-2,M-4	
205	5.73	145.0	108.0	45	F-2,F-4	
206	5.73	145.0	252.0	45	E-2,E-6	
207	5.32	90.0	0	45	F-2	
208	0.69	90.0	180.0	45	E-10	
209	0.51	45.0	90.0	45	A-5,N-5	
210	0.20	45.0	270.0	45	N-5	
211	0.50	0	undefined	45	N-6	
212	0.32	90.0	270.0	45	E-10	
213	0.20	135.0	90.0	45	A-5	
214	0.50	90.0	90.0	45	A-5	
215	0.32	180.0	undefined	45	D-10	
216	0.69	90.0	0	45	E-1	
217	0.0436	90.0	180.0	45	A-5	
218	0.139	90.0	194.0	45	A-5	
219	0.0436	0	undefined	45	A-5	
220	0.139	14.0	270.0	45	A-5	
221	0.0436	90.0	0	45	A-5	
222	0.139	90.0	346.0	45	A-5	
223	0.0436	180.0	undefined	45	B-5	
224	0.139	166.0	270.0	45	B-5	
225	0.165	90.0	90.0	45	A-5	
226	0.0436	180.0	undefined	45	D-10	
227	0.139	166.0	0	45	D-10	
228	0.0436	90.0	270.0	45	E-11	
229	0.139	90.0	284.0	45	E-11	
230	0.0436	0	undefined	45	D-10	
231	0.139	14.0	0	45	D-10	
232	0.0436	90.0	90.0	45	D-10	
233	0.139	90.0	76.0	45	D-10	
234	0.165	90.0	180.0	45	D-10	
235	0.0436	180.0	undefined	45	D-1	
236	0.139	166.0	180.0	45	D-1	
237	0.0436	90.0	90.0	45	D-1	
238	0.139	90.0	104.0	45	D-1	
239	0.0436	0	undefined	45	D-1	
240	0.139	14.0	180.0	45	D-1	
241	0.0436	90.0	270.0	45	E-1	
242	0.139	90.0	256.0	45	E-1	
243	0.165	90.0	0	45	D-1	
244	0.0436	90.0	180.0	45	N-5	
245	0.139	104.0	180.0	45	N-5	
246	0.0436	90.0	270.0	45	N-5	
247	0.139	104.0	270.0	45	N-5	
248	0.0436	90.0	0	45	N-5	
249	0.139	104.0	0	45	N-5	
250	0.0436	90.0	90.0	45	N-5	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale ($ft.^2$)	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						1-322 ARE LOCATED ON THE LEM ASCENT STAGE (DRAWING 2846-45)
251	0.139	104.0	90.0	2846-45	N-5	
252	0.165	0	undefined	45	N-5	
253	0.69	90.0	180.0	45	G-10	
254	0.51	45.0	270.0	45	K-5	
255	0.20	135.0	270.0	45	K-5	
256	0.50	90.0	270.0	45	K-5	
257	0.32	180.0	undefined	45	G-10	
258	0.20	45.0	90.0	45	L-5	
259	0.50	0	undefined	45	L-5	
260	0.32	90.0	90.0	45	F-10	
261	0.69	90.0	0	45	G-1	
262	0.0436	90.0	180.0	45	K-5	
263	0.139	90.0	166.0	45	K-5	
264	0.0436	180.0	undefined	45	J-5	
265	0.139	166.0	90.0	45	J-5	
266	0.0436	90.0	0	45	K-5	
267	0.139	90.0	14.0	45	K-5	
268	0.0436	0	undefined	45	K-5	
269	0.139	14.0	90.0	45	K-5	
270	0.165	90.0	270.0	45	K-5	
271	0.0436	90.0	270.0	45	G-10	
272	0.139	90.0	284.0	45	G-10	
273	0.0436	0	undefined	45	G-10	
274	0.139	14.0	0	45	G-10	
275	0.0436	90.0	90.0	45	F-11	
276	0.139	90.0	76.0	45	F-11	
277	0.0436	180.0	undefined	45	G-10	
278	0.139	166.0	0	45	G-10	
279	0.165	90.0	180.0	45	G-10	
280	0.0436	0	undefined	45	G-1	
281	0.139	14.0	180.0	45	G-1	
282	0.0436	90.0	270.0	45	G-1	
283	0.139	90.0	256.0	45	G-1	
284	0.0436	180.0	undefined	45	G-1	
285	0.139	166.0	180.0	45	G-1	
286	0.0436	90.0	90.0	45	F-1	
287	0.139	90.0	104.0	45	F-1	
288	0.165	90.0	0	45	G-1	
289	0.0436	90.0	180.0	45	L-6	
290	0.139	104.0	180.0	45	L-6	
291	0.0436	90.0	270.0	45	L-5	
292	0.139	104.0	270.0	45	L-5	
293	0.0436	90.0	0	45	L-5	
294	0.139	104.0	0	45	L-5	
295	0.0436	90.0	90.0	45	L-5	
296	0.139	104.0	90.0	45	L-5	
297	0.165	0	undefined	45	L-5	
298	3.90	90.0	45.0	45	A-5,E-1	
299	2.89	90.0	72.8	45	A-5,E-1	
300	3.10	90.0	270.0	45	J-6	300 Area was Approximated by a Circle
301	3.17	171.0	180.0	45	F-7	301 Area Approximated by a Circle
302	1.17	90.0	90.0	45	E-6	
303	1.17	90.0	270.0	45	F-6	
304	1.17	171.0	180.0	45	F-6	
305	0.90	142.0	0	45	F-6	
306	1.39	90.0	270.0	45	I-6	
307	0.80	58.0	180.0	45	F-8	
308	0.76	97.0	101.0	45	F-8	
309	0.76	97.0	259.0	45	E-8	
310	0.90	142.0	0	45	E-6	
311	1.39	90.0	90.0	45	C-6	
312	0.80	58.0	180.0	45	E-8	
313	1.17	9.0	0	45	M-6	
314	0.92	9.0	0	45	M-7	
315	2.24	9.0	0	45	M-7	315 Area Approximated by a Circle
316	3.10	90.0	90.0	45	B-6	316 Area Approximated by a Circle
317	0.84	90.0	90.0	45	B-6	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						1-322 ARE LOCATED ON THE LEM ASCENT STAGE (DRAWING 2846-45)
318	0.45	180.0	undefined	2846-45	B-6	
319	0.45	0	undefined	45	B-6	
320	0.84	90.0	270.0	45	D-6	
321	0.35	90.0	90.0	45	D-5	
322	0.35	90.0	270.0	45	E-6	
						323-405 ARE LOCATED ON THE LEM DESCENT STAGE (DRAWING 2846-46)
323	16.87	90.0	180.0	2846-46	F-5	323 Includes Ladder Platform 323-330 Exclude the Circle at their Apex
324	20.24	90.0	180.0	46	G-6	
325	15.62	90.0	180.0	46	G-6	
326	20.24	90.0	180.0	46	G-7	
327	15.62	90.0	180.0	46	F-7	
328	20.24	90.0	180.0	46	F-7	
329	15.62	90.0	180.0	46	E-6	
330	20.24	90.0	180.0	46	E-6	
331	26.76	180.0	undefined	46	F-3	
332	37.03	135.0	270.0	46	G-3,J-5	332 Area Approximated as a Flat Rectangular Surface
333	32.37	90.0	270.0	46	J-6	
334	21.55	48.0	253.0	46	G-10,J-7	334 Area Approximated as a Flat Rectangular Surface
335	32.37	0	undefined	46	F-10	
336	37.03	45.0	90.0	46	C-7,E-10	336 Area Approximated as a Flat Rectangular Surface
337	26.76	90.0	90.0	46	C-6	
338	37.03	135.0	90.0	46	C-5,E-3	338 Area Approximated as a Flat Rectangular Surface
339						
339	8.36	45.0	270.0	46	G-10,J-7	
340	16.88	90.0	0	46	O-7	
341	2.56	0	undefined	46	O-7	
342	6.69	15.0	180.0	46	A-7,F-11, K-7,O-7	
343	16.13	90.0	0	46	P-7	
344	2.71	45.0	90.0	46	P-7	
345	6.69	62.0	109.0	46	P-7	
346	15.56	90.0	0	46	P-6	
347	2.56	90.0	90.0	46	P-6	
348	16.13	90.0	0	46	P-5,P-6	
349	2.71	135.0	90.0	46	P-5	
350	6.69	118.0	109.0	46	P-6	
351	15.56	90.0	0	46	O-5	
352	2.56	180.0	undefined	46	O-5	
353	6.69	165.0	180.0	46	A-6,F-1, K-6,O-6	
354	16.13	90.0	0	46	N-5	
355	2.71	135.0	270.0	46	N-5	
356	6.69	118.0	251.0	46	N-6	
357	16.88	90.0	0	46	N-6	
358	2.56	90.0	270.0	46	N-6	
359	15.62	90.0	0	46	N-7,O-7	
360	0.94	74.0	0	46	N-7	
361	1.31	90.0	0	46	N-7	
362	0.94	106.0	0	46	N-7	
363	2.71	45.0	270.0	46	N-8	
364	6.69	62.0	251.0	46	O-7	
365	17.83	90.0	0	46	O-6	
366	3.28	90.0	243.5	46	H-6,K-7	
367	1.04	90.0	243.5	46	I-6,L-7	
368	3.28	180.0	undefined	46	I-2	
369	1.04	180.0	undefined	46	I-1	
370	3.28	90.0	63.5	46	M-6	
371	1.04	90.0	63.5	46	M-7	
372	3.28	0	undefined	46	I-10	
373	1.04	0	undefined	46	I-11	
374	7.10	90.0	180.0	46	I-6	
375	8.75	90.0	0	46	L-6	
376	3.28	153.5	180.0	46	E-1,G-4	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Location of Surface Element Λ_n (degrees)	Node Location Drawing Number	Node Location Location Code	Notes
						323-405 ARE LOCATED ON THE LEM DESCENT STAGE (DRAWING 2846-46)
377	1.04	153.5	180.0	2846-46	F-1,G-4	
378	3.28	90.0	90.0	46	B-4	
379	1.04	90.0	90.0	46	A-3	
380	3.28	26.5	0	46	P-4	
381	1.04	26.5	0	46	P-4	
382	3.28	90.0	270.0	46	J-4	
383	1.04	90.0	270.0	46	K-3	
384	7.10	90.0	180.0	46	F-3	
385	8.75	90.0	0	46	O-3	
386	3.28	90.0	116.5	46	A-5,D-6	
387	1.04	90.0	116.5	46	A-6,C-6	
388	3.28	0	undefined	46	D-10	
389	1.04	0	undefined	46	C-11	
390	3.28	90.0	296.5	46	Q-6	
391	1.04	90.0	296.5	46	Q-6	
392	3.28	180.0	undefined	46	D-1	
393	1.04	180.0	undefined	46	C-2	
394	7.10	90.0	180.0	46	C-6	
395	8.75	90.0	0	46	R-6	
396	3.28	26.5	180.0	46	G-9,G-11	
397	1.04	26.5	180.0	46	G-9,G-11	
398	3.28	90.0	270.0	46	J-9	
399	1.04	90.0	270.0	46	K-9	
400	3.28	153.5	0	46	P-9	
401	1.04	153.5	0	46	P-9	
402	3.28	90.0	90.0	46	B-9	
403	1.04	90.0	90.0	46	B-9	
404	7.10	90.0	180.0	46	F-9	
405	8.75	90.0	0	46	O-9	
						406-565 ARE LOCATED ON THE COMMAND MODULE (DRAWING 2846-47)
406	2.35	33.0	0	2846-47	I-2	
407	0.61	157.0	0	47	H-2	407 Area on the Command Module under the Conduit was Excluded
408	0.67	33.0	0	47	C-3	408-544 Depressions such as Windows and Pitch Ports were Excluded in Area Calculations
409	1.84	33.0	0	47	C-4	
410	1.91	33.0	0	47	C-4	
411	1.61	33.0	0	47	C-4	
412	1.61	35.53	339.57	47	C-4	
413	1.91	35.53	339.57	47	C-4	
414	1.84	35.53	339.57	47	C-4	
415	0.67	35.53	339.57	47	D-3	
416	2.36	35.53	339.57	47	D-4	
417	0.67	14.0	270.0	47	D-3	
418	0.72	28.5	270.0	47	D-3	
419	2.50	42.52	323.70	47	D-4	
420	0.69	42.52	323.70	47	D-3	
421	1.91	42.52	323.70	47	D-4	
422	1.98	42.50	323.70	47	D-4	
423	1.68	42.50	323.70	47	D-4	
424	2.01	53.63	312.57	47	D-4	
425	2.39	53.63	312.57	47	D-4	
426	2.33	53.63	312.57	47	D-4	
427	0.83	53.63	312.57	47	E-4	
428	2.99	53.63	312.57	47	D-4	
429	0.87	45.0	270.0	47	D-4	
430	0.67	61.0	270.0	47	E-4	
431	2.36	66.0	306.6	47	D-4	
432	0.67	66.0	306.6	47	E-4	
433	1.84	66.0	306.6	47	D-4	
434	1.91	66.0	306.6	47	D-4	
435	1.61	66.0	306.6	47	D-5	
436	1.61	77.48	303.85	47	D-5	
437	1.91	77.48	303.85	47	D-5	
438	1.84	77.48	303.85	47	D-5	
439	0.67	77.48	303.85	47	E-5	
440	2.36	77.48	303.85	47	E-5	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Location of Surface Element A_n (degrees)	Node Location Drawing Number	Node Location Location Code	Notes
						406-565 ARE LOCATED ON THE COMMAND MODULE (DRAWING 2846-47)
441	0.67	75.0	270.0	2846-47	E-4	
442	0.73	90.0	270.0	47	E-5	
443	1.04	90.0	303.0	47	E-5	
444	1.60	90.0	303.0	47	E-5	
445	0.76	90.0	303.0	47	E-5	
446	2.05	90.0	303.0	47	D-5	
447	2.12	90.0	303.0	47	D-5	
448	1.80	90.0	303.0	47	D-5	
449	1.48	102.52	303.85	47	D-5	
450	1.78	102.52	303.85	47	D-5	
451	1.72	102.52	303.85	47	D-5	
452	0.62	102.52	303.85	47	E-5	
453	2.15	102.52	303.85	47	E-5	
454	0.62	104.5	270.0	47	E-5	
455	0.70	118.0	270.0	47	E-6	
456	2.43	113.18	306.33	47	E-6	
457	1.11	116.78	307.60	47	E-6	
458	3.02	116.78	307.60	47	D-6	
459	3.07	116.78	307.60	47	D-5	
460	2.61	116.78	307.60	47	D-5	
461	2.48	133.40	318.55	47	D-5	
462	2.94	133.40	318.55	47	D-6	
463	2.88	133.40	318.55	47	D-6	
464	1.04	133.40	318.55	47	D-7	
465	2.57	125.27	311.83	47	D-6	
466	0.73	133.5	270.0	47	E-6	
467	0.72	149.0	270.0	47	D-7	
468	2.50	135.97	321.58	47	D-6	
469	0.73	164.0	270.0	47	D-7	
470	2.64	143.27	334.88	47	D-6	
471	0.76	143.27	334.88	47	D-7	
472	2.05	143.27	334.88	47	D-6	
473	2.12	143.27	334.88	47	C-6	
474	1.80	143.27	334.88	47	C-6	
475	1.80	147.0	0	47	C-6	
476	2.12	147.0	0	47	C-6	
477	2.05	147.0	0	47	C-6	
478	0.76	147.0	0	47	D-7	
479	1.60	147.0	0	47	C-6	
480	1.04	147.0	0	47	C-7	
481	0.73	180.0	undefined	47	C-7	
482	0.73	164.0	90.0	47	C-7	
483	2.64	143.27	25.12	47	C-6	
484	0.76	143.27	25.12	47	C-7	
485	2.05	143.27	25.12	47	C-6	
486	2.12	143.27	25.12	47	C-6	
487	1.80	143.27	25.12	47	C-6	
488	2.49	133.40	41.45	47	C-5	
489	2.94	133.40	41.45	47	C-6	
490	2.88	133.40	41.45	47	C-6	
491	1.04	133.40	41.45	47	B-6	
492	2.57	135.97	38.42	47	B-6	
493	0.73	149.0	90.0	47	B-6	
494	0.72	133.5	90.0	47	B-6	
495	2.57	125.27	48.17	47	B-6	
496	0.68	118.0	90.0	47	B-6	
497	2.36	113.18	53.67	47	B-6	
498	1.11	116.78	52.40	47	B-6	
499	3.02	116.78	52.40	47	B-6	
500	3.07	116.78	52.40	47	B-5	
501	2.61	116.78	52.40	47	C-5	
502	1.48	102.52	56.15	47	C-5	
503	1.78	102.52	56.15	47	B-5	
504	1.72	102.52	56.15	47	B-5	
505	0.62	102.52	56.15	47	B-5	
506	2.15	102.52	56.15	47	B-5	
507	0.62	104.50	90.0	47	A-5	
508	0.73	90.0	90.0	47	A-5	
509	1.04	90.0	57.0	47	A-5	
510	1.60	90.0	57.0	47	B-5	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale ($ft.^2$)	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						406-565 ARE LOCATED ON THE COMMAND MODULE (DRAWING 2846-47)
511	0.76	90.0	57.0	2746-47	A-5	
512	2.05	90.0	57.0	47	B-5	
513	2.12	90.0	57.0	47	B-5	
514	1.80	90.0	57.0	47	C-5	
515	1.61	77.48	56.15	47	C-5	
516	1.91	77.48	56.15	47	B-5	
517	1.84	77.48	56.15	47	B-5	
518	0.67	77.48	56.15	47	A-5	
519	2.36	77.48	56.15	47	B-5	
520	0.67	75.0	90.0	47	A-4	
521	0.67	61.0	90.0	47	B-4	
522	2.36	66.0	53.40	47	B-4	
523	0.67	66.0	53.40	47	B-4	
524	1.84	66.0	53.40	47	B-4	
525	1.91	66.0	53.40	47	B-4	
526	1.61	66.0	53.40	47	C-5	
527	2.01	53.63	47.43	47	C-4	
528	2.39	53.63	47.43	47	C-4	
529	2.33	53.63	47.43	47	B-4	
530	0.83	53.63	47.43	47	B-4	
531	2.99	53.63	47.43	47	B-4	
532	0.87	45.0	90.0	47	B-4	
533	0.72	28.50	90.0	47	B-3	
534	2.50	42.52	36.30	47	C-4	
535	0.69	42.52	36.30	47	B-3	
536	1.91	42.52	36.30	47	C-4	
537	1.97	42.52	36.30	47	C-4	
538	1.68	42.52	36.30	47	C-4	
539	1.61	35.53	20.43	47	C-4	
540	2.94	35.53	20.43	47	C-4	
541	1.84	35.53	20.43	47	C-4	
542	0.67	35.53	20.43	47	C-3	
543	2.36	35.53	20.43	47	C-4	
544	0.67	14.0	90.0	47	C-3	
545	0.405	135.0	270.0	47	F-2	
546	0.405	135.0	90.0	47	F-2	
547	0.405	45.0	90.0	47	F-1	
548	0.405	45.0	270.0	47	G-1	
549	0.243	68.0	67.0	47	G-3	
550	0.243	44.0	200.0	47	G-3	
551	0.243	118.0	240.0	47	G-3	
552	0.243	141.0	30.0	47	H-3	
553	0.243	70.5	300.5	47	G-3	
554	0.243	118.0	236.0	47	G-3	
555	0.243	135.0	130.0	47	G-3	
556	0.243	70.5	63.5	47	H-3	
557	0.243	145.0	325.0	47	G-3	
558	0.243	112.0	112.0	47	G-3	
559	0.243	76.0	311.0	47	H-3	
560	0.243	19.0	193.0	47	G-3	
561	6.45	90.0	0	47	E-2	
562	2.74	0	undefined	47	I-2	
563	2.42	32.5	180.0	47	J-2	
564	2.90	90.0	83.33	47	I-2	
565	2.90	90.0	276.67	47	I-3	
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
566	0.772	85.25	90.0	2846-48	H-4	566-729 Ω_b and Λ_b were calculated by Transformation Equations
567	0.328	81.20	180.0	48	H-4	
568	0.772	70.75	270.0	48	H-4	
569	0.328	81.20	0	48	I-4	
570	0.339	7.25	90.0	48	I-4	
571	0.0436	52.25	90.0	48	I-4	
572	0.139	61.25	70.70	48	I-4	
573	0.0436	37.80	270.0	48	I-4	
574	0.139	47.80	294.0	48	I-4	
575	0.0436	127.75	270.0	48	J-4	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Location of Surface Element Λ_n (degrees)	Node Location Drawing Number	Node Location Location Code	Notes
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
576	0.139	128.60	291.1	2846-48	J-4	
577	0.0436	142.20	90.0	48	J-4	
578	0.139	141.80	62.7	48	J-4	
579	0.165	81.20	180.0	48	J-4	
580	0.0436	45.5	7.5	48	J-4	
581	0.139	42.7	336.9	48	K-4	
582	0.0436	45.5	172.5	48	K-4	
583	0.139	42.7	203.1	48	K-4	
584	0.0436	134.5	187.5	48	K-4	
585	0.139	132.6	210.5	48	K-4	
586	0.0436	134.5	352.5	48	K-4	
587	0.139	132.6	329.5	48	L-4	
588	0.165	85.25	90.0	48	L-4	
589	0.0436	37.8	270.0	48	L-4	
590	0.139	47.8	248.2	48	L-4	
591	0.0436	52.25	90.0	48	L-4	
592	0.139	61.25	109.3	48	L-4	
593	0.0436	142.2	90.0	48	M-4	
594	0.139	141.8	117.3	48	M-4	
595	0.0436	127.75	270.0	48	M-4	
596	0.139	128.6	248.9	48	M-4	
597	0.165	81.2	0	48	M-4	
598	0.0436	45.5	172.5	48	M-4	
599	0.139	49.8	144.9	48	N-4	
600	0.0436	45.5	7.5	48	N-4	
601	0.139	49.8	35.1	48	N-4	
602	0.0436	134.5	352.5	48	N-4	
603	0.139	138.5	16.7	48	N-4	
604	0.0436	134.5	187.5	48	N-4	
605	0.139	138.5	163.3	48	N-4	
606	0.165	70.75	270.0	48	N-4	
607	0.772	175.25	90.0	48	H-4	
608	0.328	90.0	8.85	48	H-4	
609	0.772	19.25	90.0	48	H-4	
610	0.328	90.0	8.85	48	I-4	
611	0.339	97.25	90.0	48	I-4	
612	0.0436	142.25	90.0	48	I-4	
613	0.139	145.90	58.90	48	I-4	
614	0.0436	52.20	90.0	48	I-4	
615	0.139	47.40	65.50	48	I-4	
616	0.0436	37.75	370.0	48	J-4	
617	0.139	43.10	294.10	48	J-4	
618	0.0436	127.80	270.0	48	J-4	
619	0.139	123.35	289.85	48	J-4	
620	0.165	90.0	171.15	48	J-4	
621	0.0436	95.35	44.80	48	J-4	
622	0.139	74.60	49.65	48	K-4	
623	0.0436	95.35	135.20	48	K-4	
624	0.139	74.60	130.35	48	K-4	
625	0.0436	84.65	224.80	48	K-4	
626	0.139	68.00	226.85	48	K-4	
627	0.0436	84.65	315.20	48	K-4	
628	0.139	68.00	313.00	48	L-4	
629	0.165	175.25	90.0	48	L-4	
630	0.0436	52.20	90.0	48	L-4	
631	0.139	46.50	112.15	48	L-4	
632	0.0436	142.25	90.0	48	L-4	
633	0.139	145.90	121.10	48	L-4	
634	0.0436	127.80	270.0	48	M-4	
635	0.139	123.35	250.15	48	M-4	
636	0.0436	37.75	270.0	48	M-4	
637	0.139	43.10	246.20	48	M-4	
638	0.165	90.0	8.85	48	M-4	
639	0.0436	95.35	135.20	48	M-4	
640	0.139	116.10	134.20	48	N-4	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale ($ft.^2$)	Location of Surface Element Γ_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
641	0.0436	95.35	44.80	2846-48	N-4	
642	0.139	116.10	45.80	48	N-4	
643	0.0436	84.65	315.20	48	N-4	
644	0.139	101.00	310.35	48	N-4	
645	0.0436	84.65	224.8	48	N-4	
646	0.139	101.00	229.65	48	N-4	
647	0.165	19.25	90.0	48	N-4	
648	0.772	94.75	270.0	48	H-4	
649	0.328	98.80	0	48	H-4	
650	0.772	109.25	90.0	48	H-4	
651	0.328	98.80	0	48	I-4	
652	0.339	172.25	270.0	48	I-4	
653	0.0436	142.20	90.0	48	L-4	
654	0.139	132.20	111.75	48	L-4	
655	0.0436	127.75	270.0	48	L-4	
656	0.139	118.75	250.75	48	L-4	
657	0.0436	37.80	270.0	48	M-4	
658	0.139	38.20	242.80	48	M-4	
659	0.0436	52.25	90.0	48	M-4	
660	0.139	51.40	110.0	48	M-4	
661	0.165	98.80	0	48	M-4	
662	0.0436	134.5	352.6	48	J-4	
663	0.139	137.30	23.10	48	K-4	
664	0.0436	134.50	187.40	48	K-4	
665	0.139	137.30	156.90	48	K-4	
666	0.0436	45.50	172.60	48	K-4	
667	0.139	47.40	149.50	48	K-4	
668	0.0436	45.50	7.40	48	K-4	
669	0.139	47.40	30.50	48	L-4	
670	0.165	94.75	270.0	48	L-4	
671	0.0436	127.75	270.0	48	I-4	
672	0.139	118.75	289.25	48	I-4	
673	0.0436	142.20	90.0	48	I-4	
674	0.139	132.20	66.0	48	I-4	
675	0.0436	52.25	90.0	48	J-4	
676	0.139	51.40	69.0	48	J-4	
677	0.0436	37.80	270.0	48	J-4	
678	0.139	38.20	297.2	48	J-4	
679	0.165	98.8	180.0	48	J-4	
680	0.0436	134.50	187.40	48	M-4	
681	0.139	130.20	215.10	48	N-4	
682	0.0436	134.50	352.60	48	N-4	
683	0.139	130.20	324.90	48	N-4	
684	0.0436	45.50	7.40	48	N-4	
685	0.139	41.50	343.40	48	N-4	
686	0.0436	45.50	172.60	48	N-4	
687	0.139	41.50	196.60	48	N-4	
688	0.165	109.25	90.0	48	N-4	
689	0.772	4.75	270.0	48	H-3	
690	0.328	90.0	351.15	48	H-3	
691	0.772	160.75	270.0	48	H-3	
692	0.328	90.0	351.15	48	I-3	
693	0.339	82.25	270.0	48	I-3	
694	0.0436	37.75	270.0	48	I-3	
695	0.139	34.10	301.10	48	I-3	
696	0.0436	127.80	270.0	48	I-3	
697	0.139	132.60	294.50	48	I-3	
698	0.0436	142.25	90.0	48	J-3	
699	0.139	136.90	65.90	48	J-3	
700	0.0436	52.2	90.0	48	J-3	
701	0.139	56.65	70.25	48	J-3	
702	0.165	90.0	188.85	48	J-3	
703	0.0436	84.65	315.25	48	J-3	
704	0.139	105.40	310.3	48	K-3	
705	0.0436	84.65	224.75	48	K-3	
706	0.139	105.4	229.7	48	K-3	
707	0.0436	95.35	135.25	48	K-3	
708	0.139	112.0	133.20	48	K-3	

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	A_n (degrees)	Node Location Drawing Number	Location Code	Notes
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
709	0.0436	95.35	44.75	2846-48	K-3	
710	0.139	112.0	46.8	48	L-3	
711	0.165	4.75	270.0	48	L-3	
712	0.0436	127.80	270.0	48	L-3	
713	0.139	133.50	247.9	48	L-3	
714	0.0436	37.75	270.0	48	L-3	
715	0.139	34.1	238.9	48	L-3	
716	0.0436	52.20	90.0	48	M-3	
717	0.139	56.65	109.75	48	M-3	
718	0.0436	142.25	90.0	48	M-3	
719	0.139	136.90	114.10	48	M-3	
720	0.165	90.0	351.15	48	M-3	
721	0.0436	84.65	224.75	48	M-3	
722	0.139	63.9	225.90	48	N-3	
723	0.0436	84.65	315.25	48	N-3	
724	0.139	63.90	314.10	48	N-3	
725	0.0436	95.35	44.75	48	N-3	
726	0.139	79.0	49.70	48	N-3	
727	0.0436	95.35	135.25	48	N-3	
728	0.139	79.0	130.30	48	N-3	
729	0.165	160.75	270.0	48	N-3	
730	3.64	157.5	90.0	48	B-2	
731	3.22	157.5	90.0	48	B-2	
732	3.08	157.5	90.0	48	C-2	
733	3.08	157.5	90.0	48	C-2	
734	3.08	157.5	90.0	48	C-2	
735	3.08	157.5	90.0	48	D-2	
736	3.08	157.5	90.0	48	D-2	
737	3.08	157.5	90.0	48	D-2	
738	3.08	142.5	90.0	48	D-3	
739	3.08	142.5	90.0	48	D-3	
740	3.08	142.5	90.0	48	D-3	
741	3.08	142.5	90.0	48	C-3	
742	3.08	142.5	90.0	48	C-3	
743	3.08	142.5	90.0	48	C-3	
744	3.22	142.5	90.0	48	B-3	
745	3.64	142.5	90.0	48	B-3	
746	3.64	127.5	90.0	48	B-3	
747	3.22	127.5	90.0	48	B-3	
748	3.08	127.5	90.0	48	C-3	
749	3.08	127.5	90.0	48	C-3	
750	3.08	127.5	90.0	48	C-3	
751	3.08	127.5	90.0	48	D-3	
752	3.08	127.5	90.0	48	D-3	
753	3.08	127.5	90.0	48	D-3	
754	3.08	112.5	90.0	48	D-3	
755	3.08	112.5	90.0	48	D-3	
756	3.08	112.5	90.0	48	D-3	
757	3.08	112.5	90.0	48	C-3	
758	3.08	112.5	90.0	48	C-3	
759	3.08	112.5	90.0	48	C-3	
760	3.22	112.5	90.0	48	B-3	
761	3.64	112.5	90.0	48	B-3	
762	3.64	97.5	90.0	48	B-4	
763	3.22	97.5	90.0	48	B-4	
764	2.38	97.5	90.0	48	C-4	764 Base Area of the Reaction Control Engine is not Included in the Nodal Area
765	3.08	97.5	90.0	48	C-4	
766	3.08	97.5	90.0	48	C-4	
767	3.08	97.5	90.0	48	D-4	
768	3.08	97.5	90.0	48	D-4	
769	3.08	97.5	90.0	48	D-4	
770	3.08	82.5	90.0	48	D-4	
771	3.08	82.5	90.0	48	D-4	
772	3.08	82.5	90.0	48	D-4	
773	3.08	82.5	90.0	48	C-4	
774	3.08	82.5	90.0	48	C-4	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
775	3.08	82.5	90.0	2846-48	C-4	
776	3.22	82.5	90.0	48	B-4	
777	3.64	82.5	90.0	48	B-4	
778	3.64	67.5	90.0	48	B-4	
779	3.22	67.5	90.0	48	B-4	
780	3.08	67.5	90.0	48	C-4	
781	3.08	67.5	90.0	48	C-4	
782	3.08	67.5	90.0	48	C-4	
783	3.08	67.5	90.0	48	D-4	
784	3.08	67.5	90.0	48	D-4	
785	3.08	67.5	90.0	48	D-4	
786	3.08	52.5	90.0	48	D-5	
787	3.08	52.5	90.0	48	D-5	
788	3.08	52.5	90.0	48	D-5	
789	3.08	52.5	90.0	48	C-5	
790	3.08	52.5	90.0	48	C-5	
791	3.08	52.5	90.0	48	C-5	
792	3.22	52.5	90.0	48	B-5	
793	3.64	52.5	90.0	48	B-5	
794	3.64	37.5	90.0	48	B-5	
795	3.22	37.5	90.0	48	B-5	
796	3.08	37.5	90.0	48	C-5	
797	3.08	37.5	90.0	48	C-5	
798	3.08	37.5	90.0	48	C-5	
799	3.08	37.5	90.0	48	D-5	
800	3.08	37.5	90.0	48	D-5	
801	3.08	37.5	90.0	48	D-5	
802	3.08	22.5	90.0	48	D-5	
803	3.08	22.5	90.0	48	D-5	
804	3.08	22.5	90.0	48	D-5	
805	3.08	22.5	90.0	48	C-5	
806	3.08	22.5	90.0	48	C-5	
807	3.08	22.5	90.0	48	C-5	
808	3.22	22.5	90.0	48	B-5	
809	3.64	22.5	90.0	48	B-5	
810	1.94	12.0	90.0	48	B-6	810 Area of the Conduit is not Included in the Nodal Area
811	2.47	8.4	90.0	48	B-6	811 Area of the Conduit is not Included in the Nodal Area
812	2.38	7.5	90.0	48	C-6	812 Base Area of the Reaction Control Engine is not Included in the Nodal Area
813	3.08	7.5	90.0	48	C-6	
814	3.08	7.5	90.0	48	C-6	
815	3.08	7.5	90.0	48	D-6	
816	3.08	7.5	90.0	48	D-6	
817	3.08	7.5	90.0	48	D-6	
818	3.08	7.5	270.0	48	D-6	
819	3.08	7.5	270.0	48	D-6	
820	3.08	7.5	270.0	48	D-6	
821	3.08	7.5	270.0	48	C-6	
822	3.08	7.5	270.0	48	C-6	
823	3.08	7.5	270.0	48	C-6	
824	2.47	8.4	270.0	48	B-6	824 Area of the Conduit is not Included in the Nodal Area
825	1.94	12.0	270.0	48	B-6	825 Area of the Conduit is not Included in the Nodal Area
826	3.64	22.5	270.0	48	B-7	
827	3.22	22.5	270.0	48	B-7	
828	3.08	22.5	270.0	48	C-7	
829	3.08	22.5	270.0	48	C-7	
830	3.08	22.5	270.0	48	C-7	
831	3.08	22.5	270.0	48	D-7	
832	3.08	22.5	270.0	48	D-7	
833	3.08	22.5	270.0	48	D-7	
834	3.08	37.5	270.0	48	D-7	
835	3.08	37.5	270.0	48	D-7	
836	3.08	37.5	270.0	48	D-7	
837	3.08	37.5	270.0	48	C-7	

GEOMETRIC DATA (continued)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
838	3.08	37.5	270.0	2846-48	C-7	
839	3.08	37.5	270.0	48	C-7	
840	3.22	37.5	270.0	48	B-7	
841	3.64	37.5	270.0	48	B-7	
842	3.64	52.5	270.0	48	B-7	
843	3.22	52.5	270.0	48	B-7	
844	3.08	52.5	270.0	48	C-7	
845	3.08	52.5	270.0	48	C-7	
846	3.08	52.5	270.0	48	C-7	
847	3.08	52.5	270.0	48	D-7	
848	3.08	52.5	270.0	48	D-7	
849	3.08	52.5	270.0	48	D-7	
850	3.08	67.5	270.0	48	D-8	
851	3.08	67.5	270.0	48	D-8	
852	3.08	67.5	270.0	48	D-8	
853	3.08	67.5	270.0	48	C-8	
854	3.08	67.5	270.0	48	C-8	
855	3.08	67.5	270.0	48	C-8	
856	3.22	67.5	270.0	48	B-8	
857	3.64	67.5	270.0	48	B-8	
858	3.64	82.5	270.0	48	B-8	
859	3.22	82.5	270.0	48	B-8	
860	2.38	82.5	270.0	48	C-8	860 Base Area of the Reaction Control Engine is not Included in the Nodal Area
861	3.08	82.5	270.0	48	C-8	
862	3.08	82.5	270.0	48	C-8	
863	3.08	82.5	270.0	48	D-8	
864	3.08	82.5	270.0	48	D-8	
865	3.08	82.5	270.0	48	D-8	
866	3.08	97.5	270.0	48	D-8	
867	3.08	97.5	270.0	48	D-8	
868	3.08	97.5	270.0	48	D-8	
869	3.08 .	97.5	270.0	48	C-8	
870	3.08	97.5	270.0	48	C-8	
871	3.08	97.5	270.0	48	C-8	
872	3.22	97.5	270.0	48	B-8	
873	3.64	97.5	270.0	48	B-8	
874	3.64	112.5	270.0	48	B-9	
875	3.22	112.5	270.0	48	B-9	
876	3.08	112.5	270.0	48	C-9	
877	3.08	112.5	270.0	48	C-9	
878	3.08	112.5	270.0	48	C-9	
879	3.08	112.5	270.0	48	D-9	
880	3.08	112.5	270.0	48	D-9	
881	3.08	112.5	270.0	48	D-9	
882	3.08	127.5	270.0	48	D-9	
883	3.08	127.5	270.0	48	D-9	
884	3.08	127.5	270.0	48	D-9	
885	3.08	127.5	270.0	48	C-9	
886	3.08	127.5	270.0	48	C-9	
887	3.08	127.5	270.0	48	C-9	
888	3.22	127.5	270.0	48	B-9	
889	3.64	127.5	270.0	48	B-9	
890	3.64	142.5	270.0	48	B-9	
891	3.22	142.5	270.0	48	B-9	
892	3.08	142.5	270.0	48	C-9	
893	3.08	142.5	270.0	48	C-9	
894	3.08	142.5	270.0	48	C-9	
895	3.08	142.5	270.0	48	D-9	
896	3.08	142.5	270.0	48	D-9	
897	3.08	142.5	270.0	48	D-9	
898	3.08	157.5	270.0	48	D-10	
899	3.08	157.5	270.0	48	D-10	
900	3.08	157.5	270.0	48	D-10	
901	3.08	157.5	270.0	48	C-10	
902	3.08	157.5	270.0	48	C-10	
903	3.08	157.5	270.0	48	C-10	

GEOMETRIC DATA (concluded)

Node Number	Node Area Full Scale (ft.^{2})	Location of Surface Element Ω_n (degrees)	Λ_n (degrees)	Node Location Drawing Number	Location Code	Notes
						566-950 ARE LOCATED ON THE SERVICE MODULE (DRAWING 2846-48)
904	3.22	157.5	270.0	2846-48	B-10	
905	3.64	157.5	270.0	48	B-10	
906	3.64	172.5	270.0	48	B-10	
907	3.22	172.5	270.0	48	B-10	
908	2.38	172.5	270.0	48	C-10	908 Base Area of the Reaction Control Engine is not Included in the Nodal Area
909	3.08	172.5	270.0	48	C-10	
910	3.08	172.5	270.0	48	C-10	
911	3.08	172.5	270.0	48	D-10	
912	3.08	172.5	270.0	48	D-10	
913	3.08	172.5	270.0	48	D-10	
914	3.08	172.5	90.0	48	D-10	
915	3.08	172.5	90.0	48	D-10	
916	3.08	172.5	90.0	48	D-10	
917	3.08	172.5	90.0	48	C-10	
918	3.08	172.5	90.0	48	C-10	
919	3.08	172.5	90.0	48	C-10	
920	3.22	172.5	90.0	48	B-10	
921	3.64	172.5	90.0	48	B-10	
922	13.37	90.0	180.0	48	L-7	922-926 Excludes the Vertical Area Between the Two Circular Segments, Location Code K-8, 9; L-7, 8, 9; and M-8,9. Drawing 2846-48
923	9.14	90.0	180.0	48	M-8	
924	13.42	90.0	180.0	48	M-9	
925	11.62	90.0	180.0	48	K-10	
926	14.82	90.0	180.0	48	J-8	
927	3.99	180.0	undefined	48	J-8	
928	3.65	79.0	119.0	48	J-9	
929	4.87	30.0	124.0	48	J-10	
930	8.94	40.0	256.0	48	M-9	
931	3.58	123.0	225.0	48	N-8	
932	1.72	129.0	253.0	48	M-6	
933	1.12	58.0	180.0	48	M-6	
934	1.32	162.0	270.0	48	M-6	
935	0.83	58.0	270.0	48	M-6	
936	0.83	90.0	90.0	48	L-6	
937	3.68	90.0	90.0	48	K-7	
938	25.49	46.9	288.3	48	G-7,G-9	
939	1.92	46.9	288.3	48	G-8,G-10	939-949 Excludes the Enclosed Circle
940	25.49	20.0	48.0	48	F-7,F-10	
941	1.92	20.0	48.0	48	F-8,G-10	
942	25.49	75.1	76.3	48	F-10	
943	1.92	75.1	76.3	48	G-10	
944	25.49	133.1	71.7	48	G-11	
945	1.92	133.1	71.7	48	G-10	
946	25.49	160.0	312.0	48	G-10	
947	1.92	160.0	312.0	48	G-10	
948	25.49	104.9	283.7	48	G-7,G-10	
949	1.92	104.9	283.7	48	G-8,G-10	
950	53.12	90.0	180.0	48	G-7	

APPENDIX C

ILLUSTRATIONS TO FACILITATE DATA PREPARATION

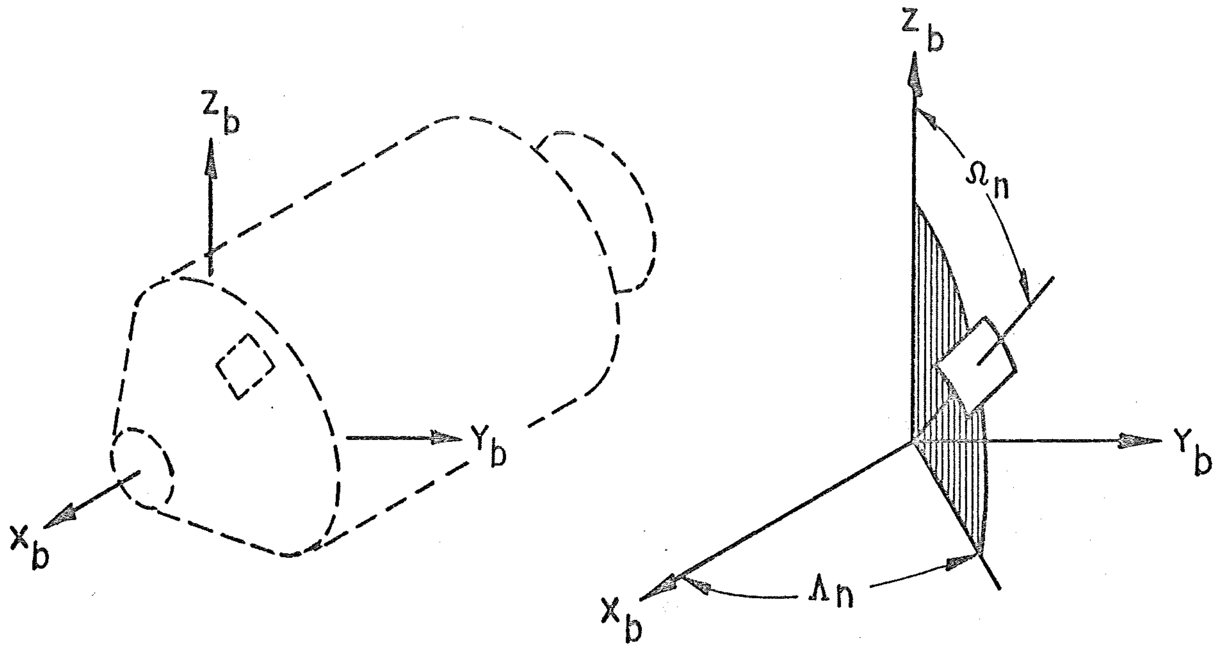


Fig. C-1 - Surface Node Coordinates, Ω_n and Λ_n

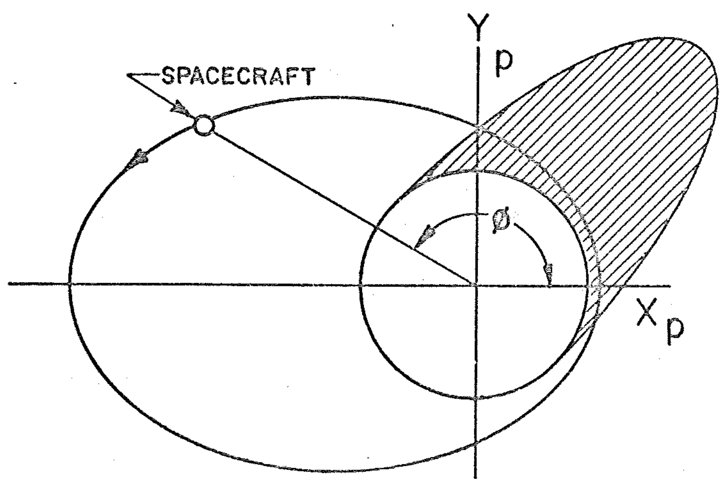


Fig. C-2 - True Anomaly, ϕ

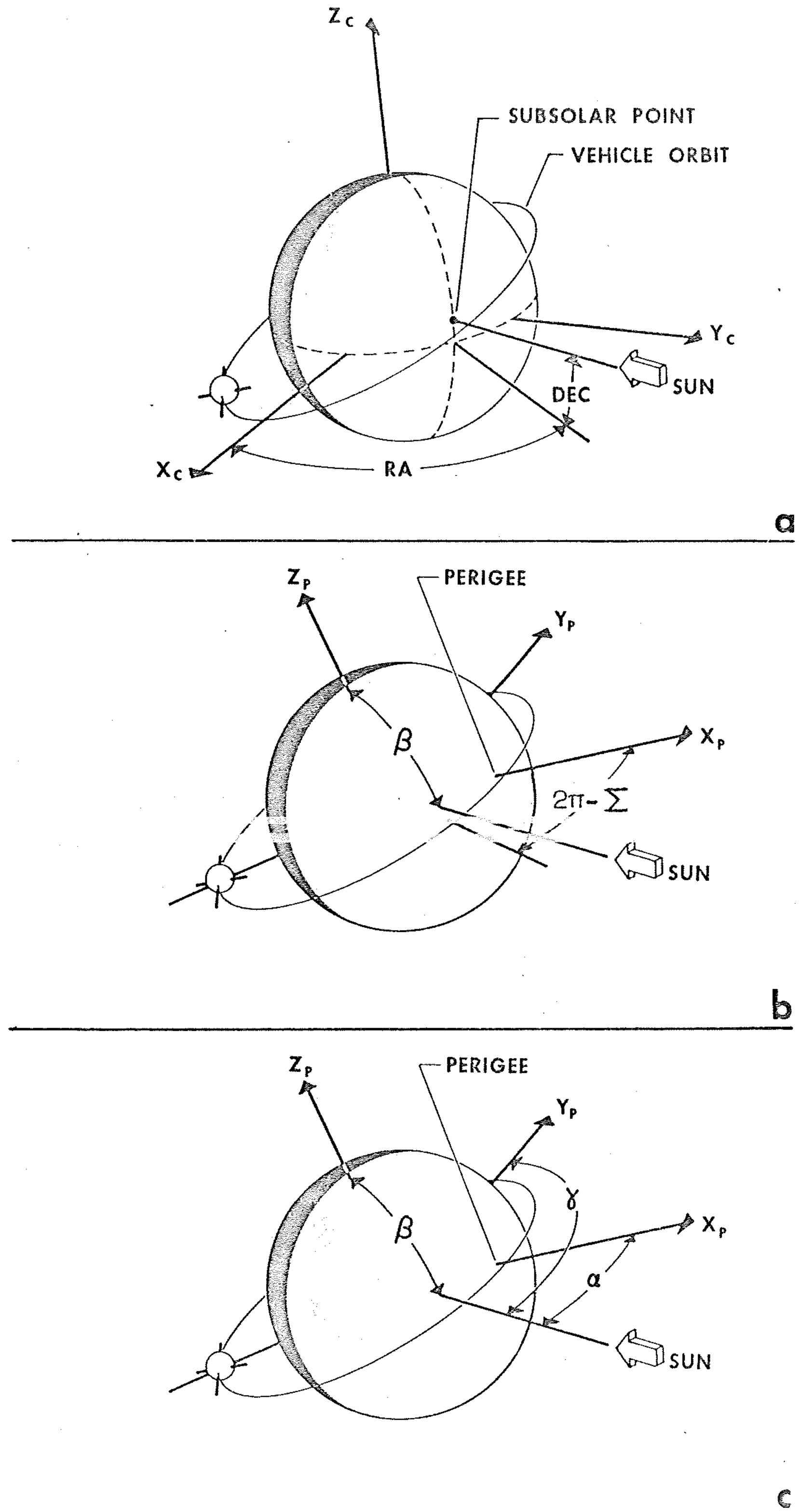


Fig. C-3 - Methods of Defining the Solar Vector

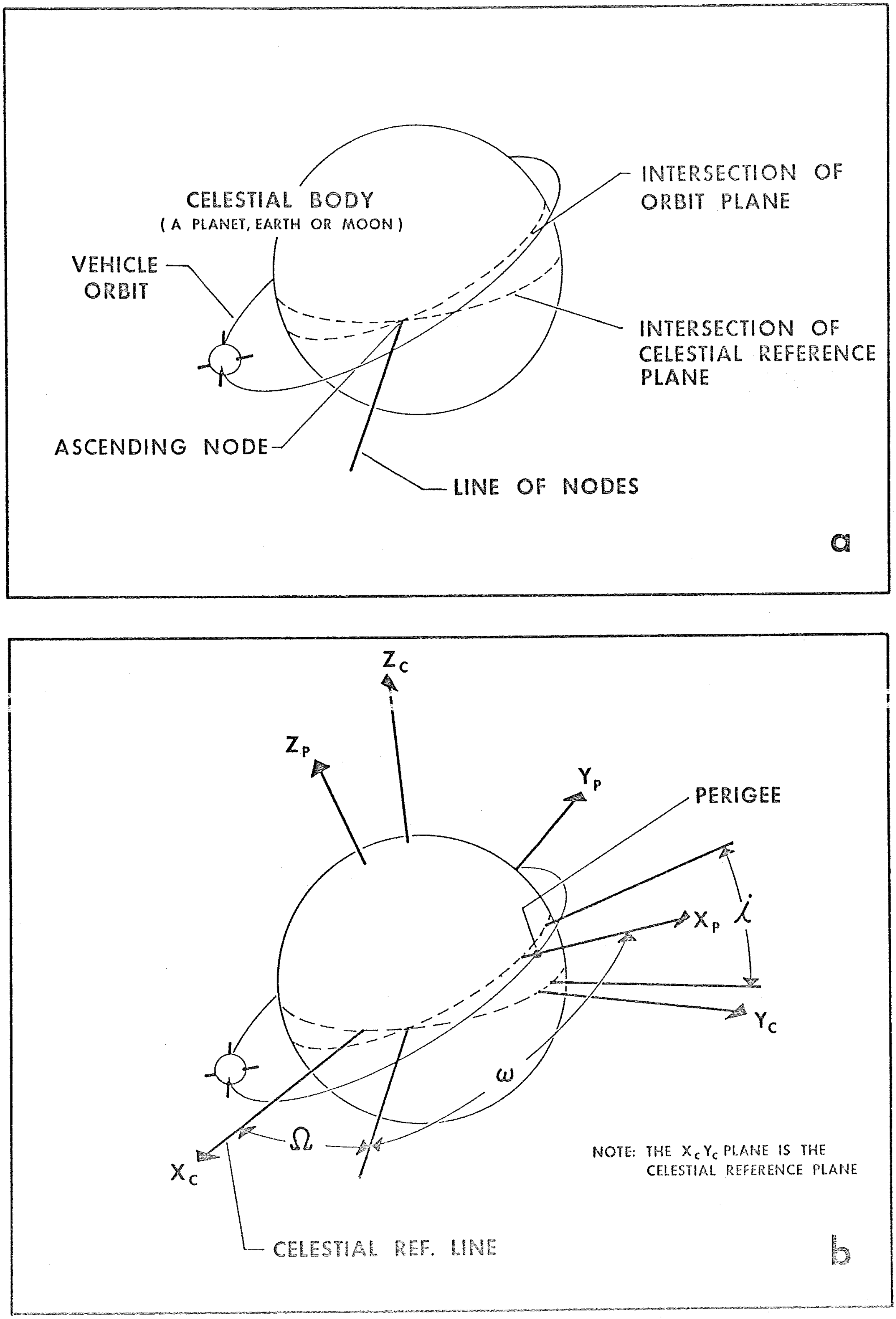


Fig. C-4 - Relationship Between Orbit and General Celestial Coordinate System

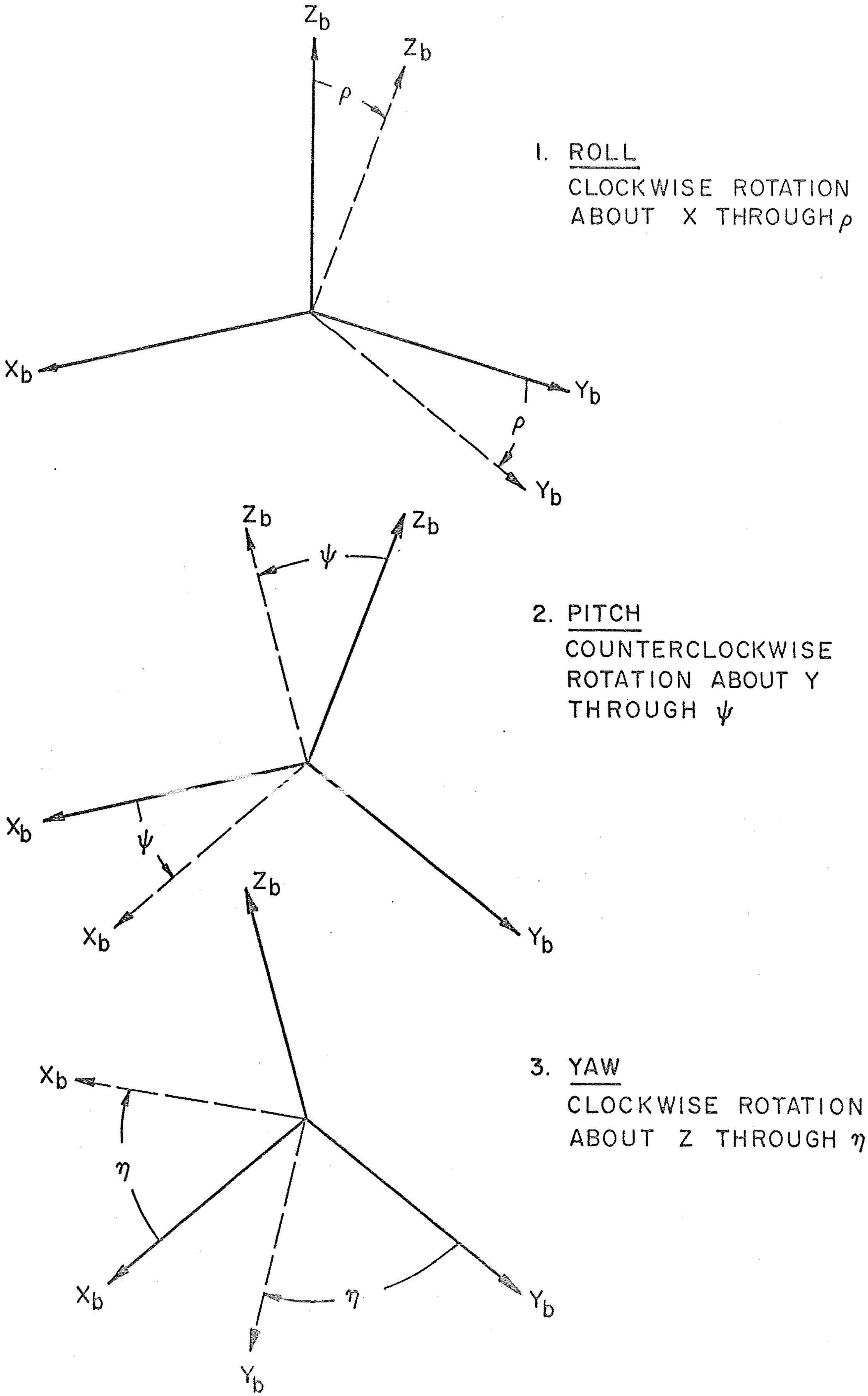


Fig. C-5 - Vehicle Attitude Coordinates, ρ , ψ , and η

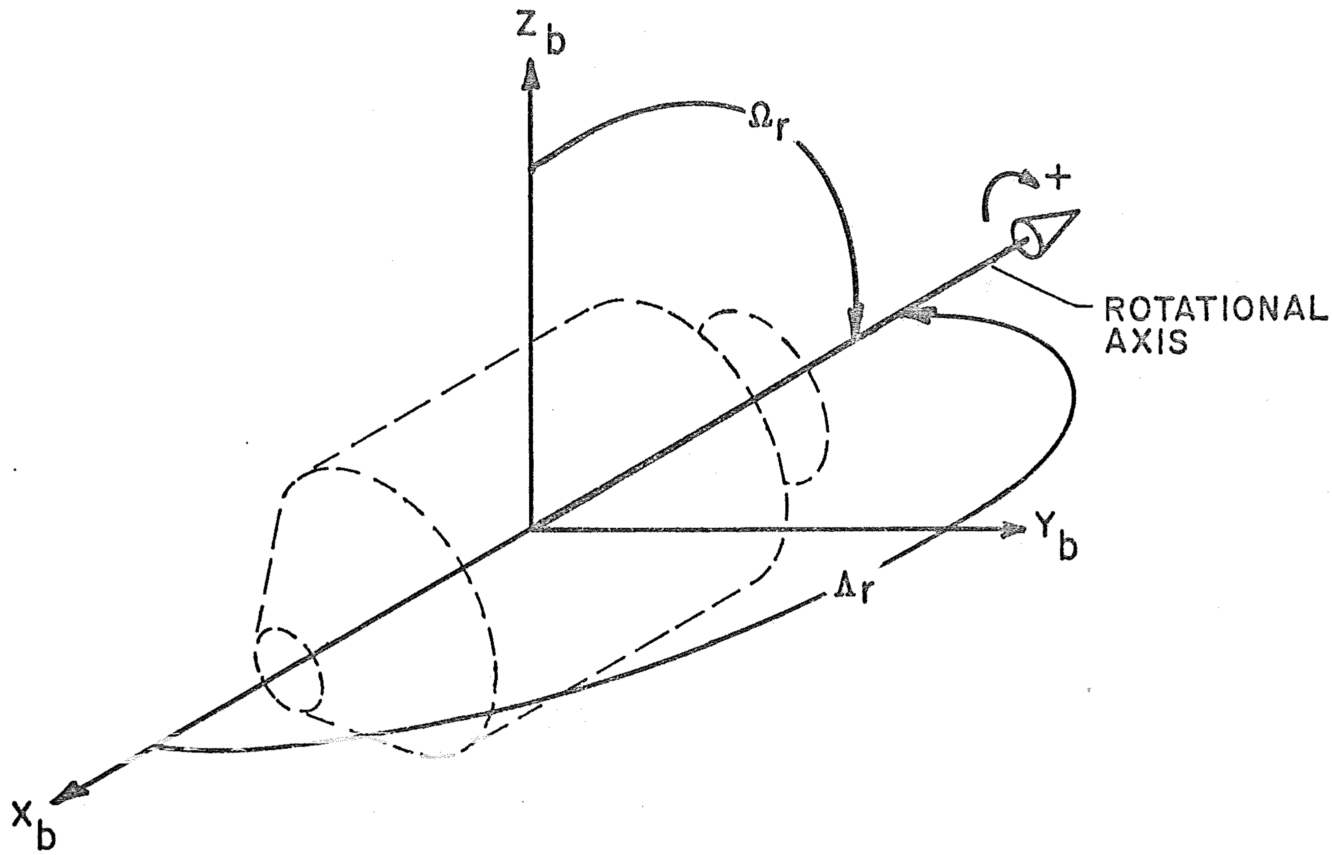


Fig. C-6 - Rotational Axis Coordinates Illustrated for the Case $\Omega_r = 90°$ and $\Lambda_r = 180°$

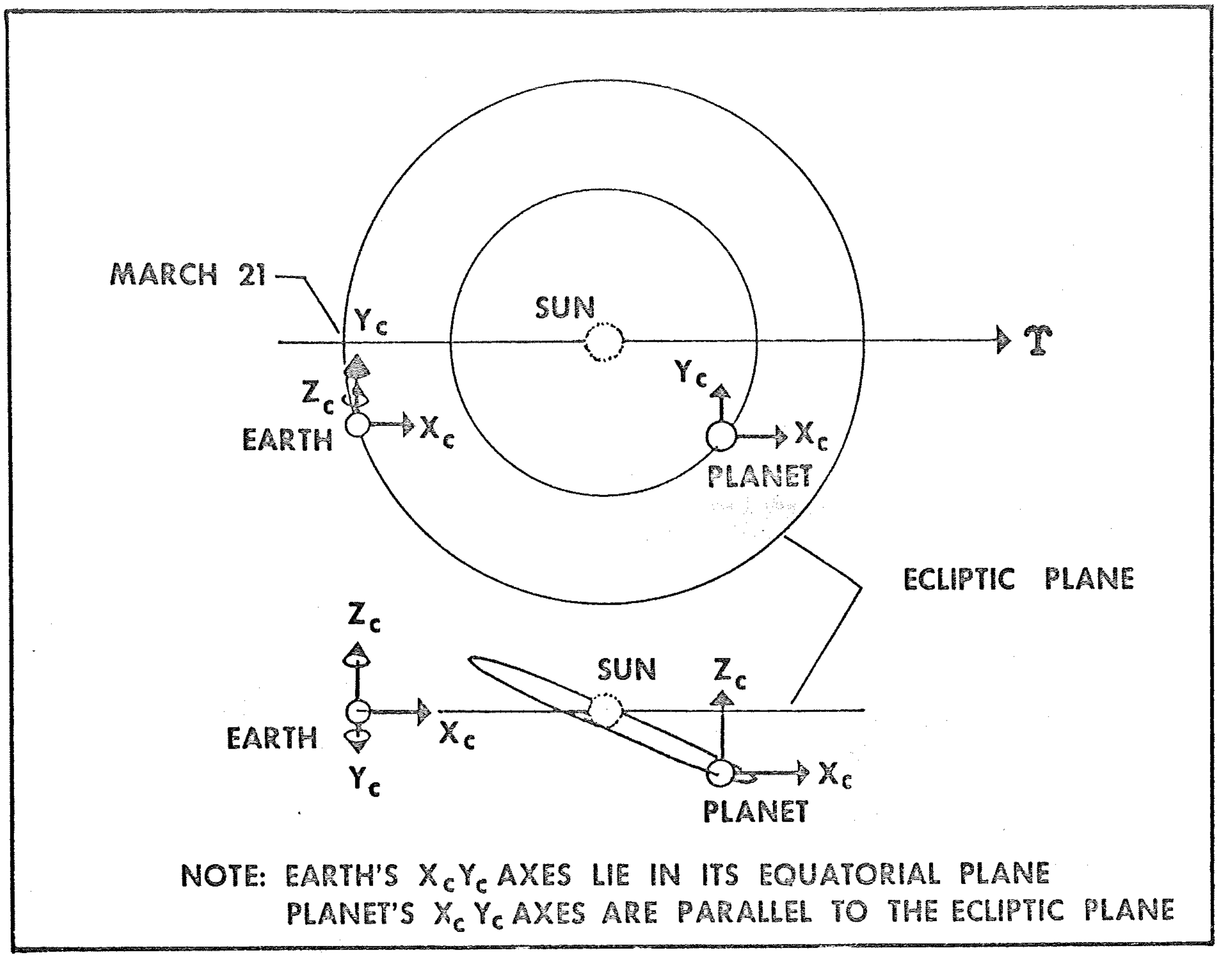


Fig. C-7 - Celestial Coordinate System for Earth (Geocentric) and Other Planets (Modified Heliocentric)

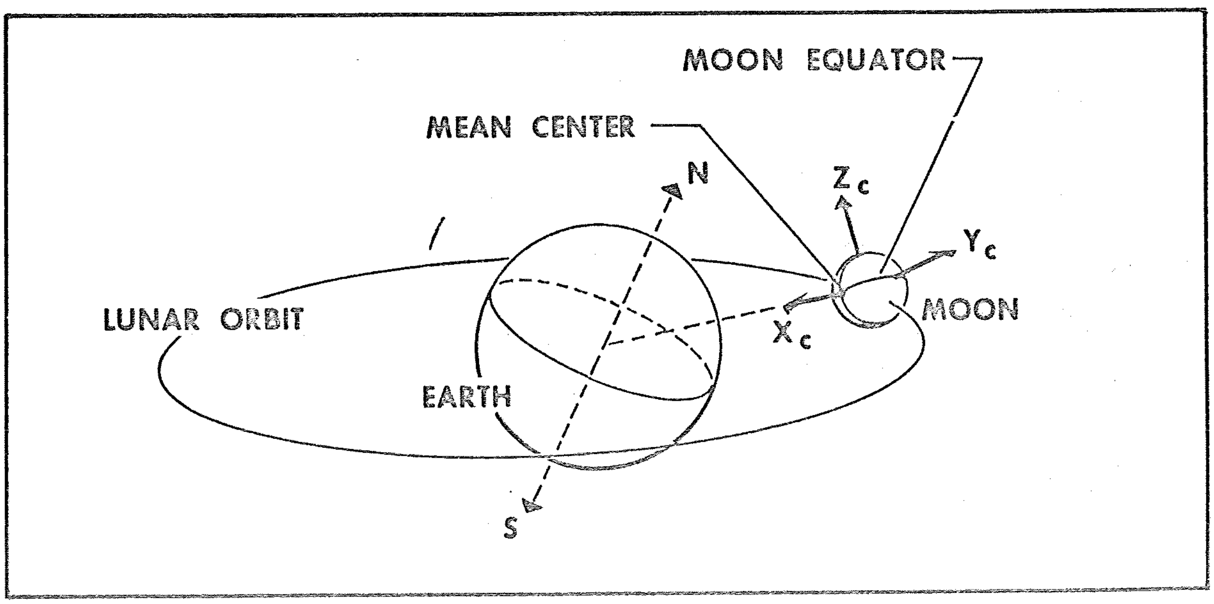


Fig. C-8 - Celestial Coordinate System for the Moon (Selenographic)

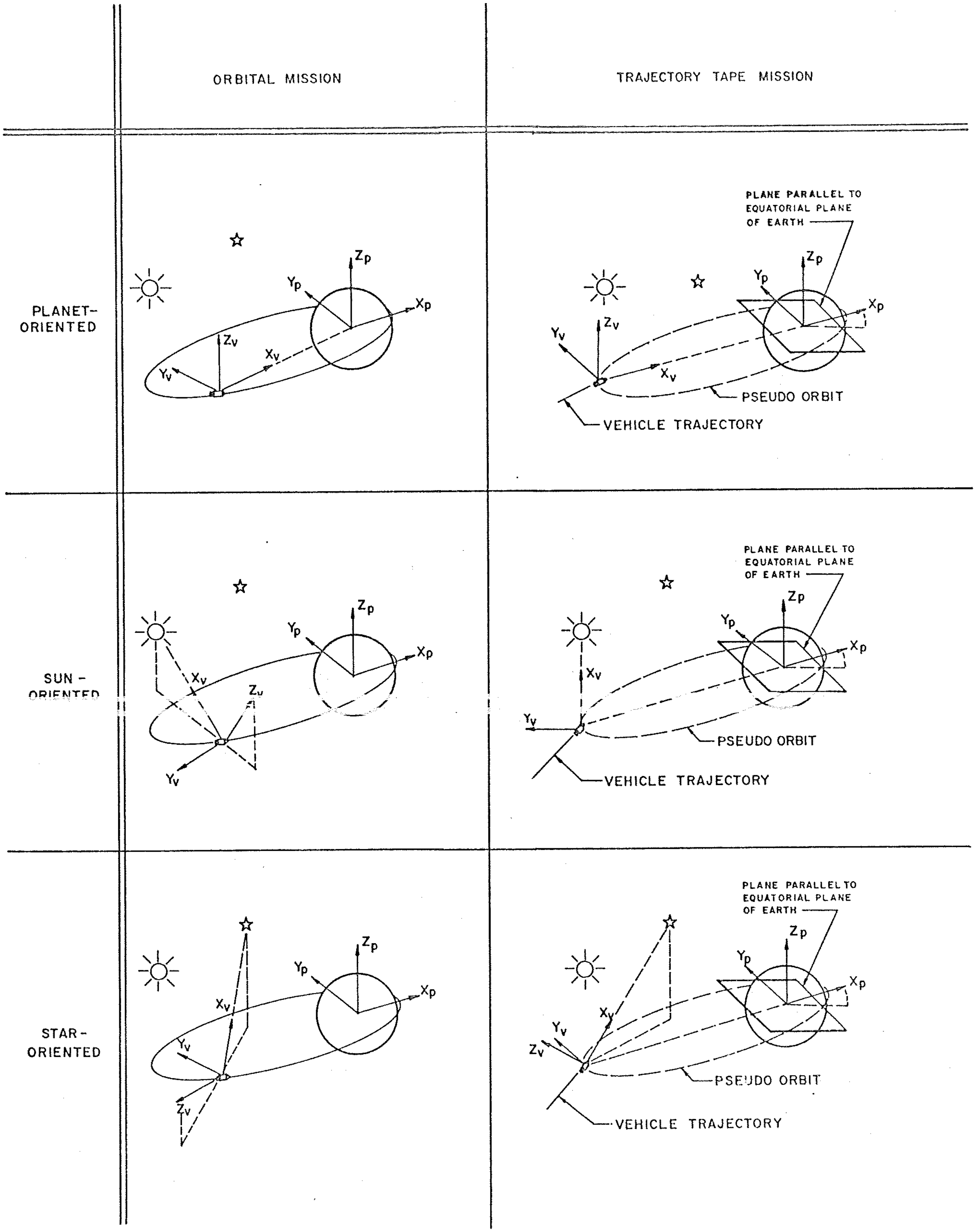


Fig. C-9 - Planet and Vehicle-Orientation Coordinate Systems

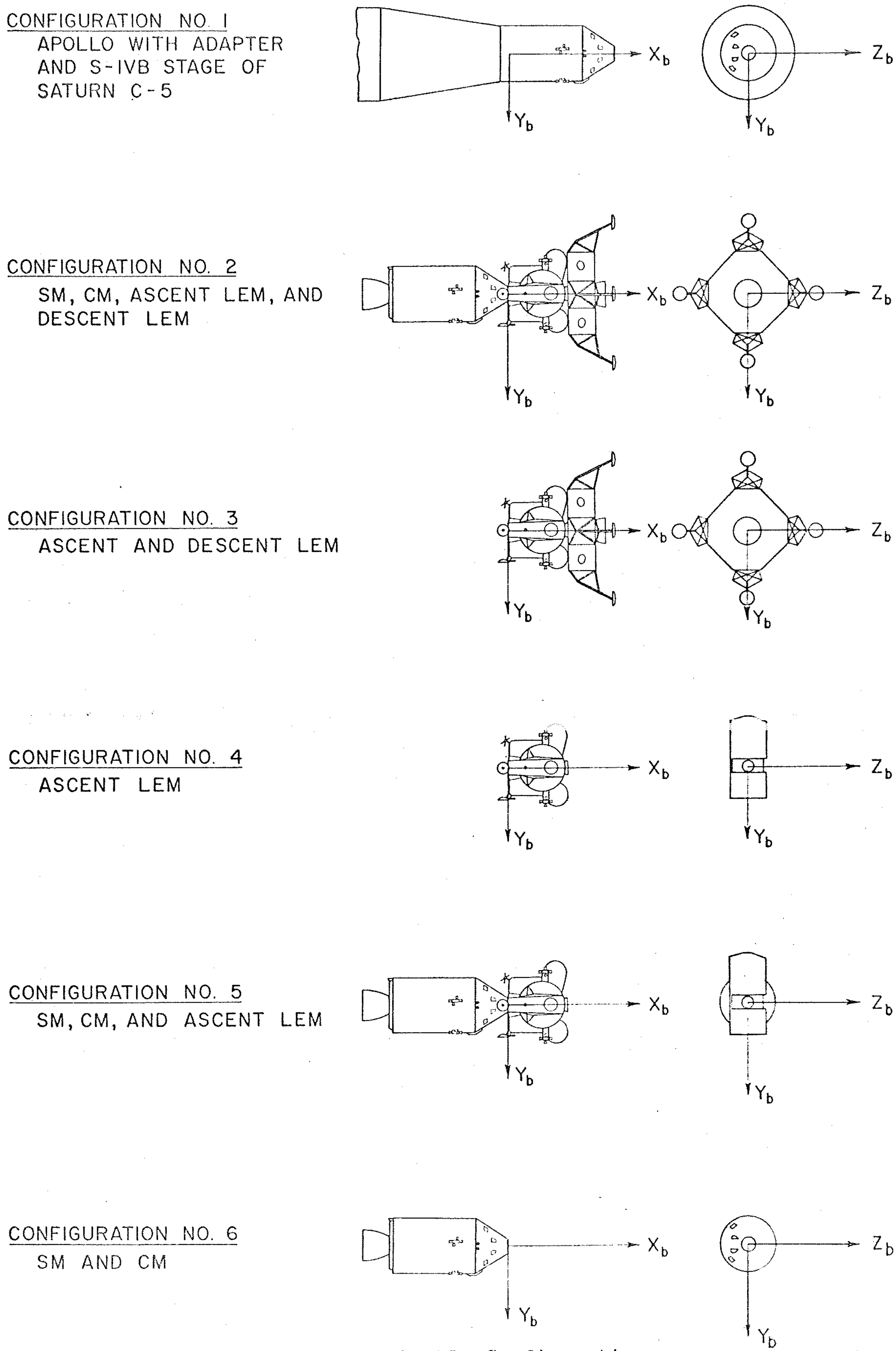


Fig. C-10 - Basic Apollo Configurations

APPENDIX D

SUMMARY OF PRINCIPAL COORDINATE SYSTEMS

SUMMARY OF PRINCIPAL COORDINATE SYSTEMS*

CELESTIAL COORDINATE SYSTEM

Type of Mission	Coordinate Basis	Definition of $+X_c$	Definition of $+Y_c$	Definition of $+Z_c$	Final Report Reference
About Earth	Geocentric, Υ Reference, Center at Earth	Parallel to and in the Same Direction as Υ	In Plane of Earth's Equator	Passes through Earth's Geographic North Pole	pp. 12, 20-22 Fig. 7
About Moon	Selenographic, Moon's Prime Meridian Reference, Center at Moon	Toward Earth	In Plane of Moon's Equator	Passes through Moon's Geographic North Pole	pp. 12, 20-22 Fig. 8
About Planet	Modified Heliocentric, Υ Reference, Center at Planet	In Same Direction as Υ, Parallel to Heliocentric X Axis	In Plane Parallel to the Elliptic	Same Half Space as in Earth's North Pole	pp. 12, 20-22 Fig. 7

PLANET COORDINATE SYSTEM

Type of Mission	Origin of Axis	Definition of $+X_p$	Definition of $+Y_p$	Definition of $+Z_p$	Final Report Reference
All	At Mass Center of Celestial Body Being Orbited	Along Major Axis of Orbital Ellipse Toward Perigee	In Orbit Plane such that Vehicle Traverses $\pi/2$ Radians in Moving from $+X_p$ to $+Y_p$	Located such that Vehicle Moves Counterclockwise when Viewed from the Positive Z_p Axis	pp. 20, 21, 23 Fig. 9

VEHICLE ORIENTATION COORDINATE SYSTEM**

Type of Mission	Origin of Axis	Definition of $+X_v$	Definition of $+Y_v$	Definition of $+Z_v$	Final Report Reference
Orbital (Planet-Oriented Vehicle)	At the Vehicle	Toward Planet	In Plane of Orbit	Parallel to and in the Same Direction as Z_p	pp. 23-25 Fig. 9
Orbital (Sun-Oriented Vehicle)	At the Vehicle	Toward Sun	In Plane of Orbit	Same Half Space as Z_p	pp. 23-25 Fig. 9
Orbital (Star-Oriented Vehicle)	At the Vehicle	Toward Star	In Plane of Orbit	Same Half Space as Z_p	pp. 23-25 Fig. 9
Trajectory Tape*** (Planet-Oriented Vehicle)	At the Vehicle	Toward Planet	Parallel to Earth's Equatorial Plane	Parallel to and in the same Direction as Z_p	pp. 23-25 Fig. 9
Trajectory Tape (Sun-Oriented Vehicle)	At the Vehicle	Toward Sun	Parallel to Earth's Equatorial Plane	Same Half Space as Earth's North Pole	pp. 23-25 Fig. 9
Trajectory Tape (Star-Oriented Vehicle)	At the Vehicle	Toward Star	Parallel to Earth's Equatorial Plane	Same Half Space as Earth's North Pole	pp. 23-25 Fig. 9

BODY COORDINATE SYSTEM

Type of Mission	Origin of Axis	Definition of $+X_b$	Definition of $+Y_b$	Definition of $+Z_b$	Final Report Reference
All	At the Vehicle	See Fig. 11, p. 29	See Fig. 11, p. 29	See Fig. 11, p. 29	pp. 25, 29 Fig. 11

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* The principal systems and those not summarized herein are all right-handed coordinate systems.
** See the pages referenced for special cases not covered by these summary definitions.
*** Trajectory Tape mission descriptions are read from an input tape, therefore, the flight paths may or may not be elliptical orbits.

APPENDIX E

PLANET DATA USED BY THE PROGRAM

Planet code numbers and the values of planet properties stored and used by the computer program are tabulated below.[a] These data may be modified for any given case by means of the 03 planet type data card (see Section III-D).

Planet Code	Planet	Distance from Sun (n.m.)[b]	Radius (n.m.)[b]	Albedo	GM_p (ft^3/sec^2)	Adjusted Cold Side Temp. (°R)[c]
1	Earth	80.4×10^6	3437.	.39	141×10^{14}	200
2	Moon	80.4×10^6	937.8	.047	1.73×10^{14}	186
3	Jupiter	419.9×10^6	37710.	.51	44900×10^{14}	50
4	Mars	123.0×10^6	1788.	.148	15.2×10^{14}	200
5	Mercury	31.3×10^6	1341.	.058	7.66×10^{14}	10
6	Neptune	$2426. \times 10^6$	13410.	.62	$2435. \times 10^{14}$	50
7	Saturn	769.5×10^6	31035.	.50	$13450. \times 10^{14}$	50
8	Uranus	$1548. \times 10^6$	13750.	.66	$2058. \times 10^{14}$	50
9	Venus	58.3×10^6	3345.	.76	114.8×10^{14}	200

---

a/ "Distance from sun" and moon's mass data from Fowle.[3] Radius, mass and albedo data from Ehricke,[4] except the albedo values for the earth and moon were specified by the NASA Project Engineer.

b/ Values stored in the program are in feet; values in the above table are in nautical miles but are equivalent to those stored within the program.

c/ Cold side temperatures are used only with the variable planet temperature option, which was developed especially for celestial bodies that have a negligible atmosphere (e.g. the moon). If this method is used for other bodies, the predicted temperature gradients may be too large because atmospheric conduction and convection is neglected. The program makes some compensation by employing "adjusted" cold side temperatures which were specified by the NASA Project Engineer; however, it is recommended that the variable temperature method be employed primarily for bodies like the moon (i.e., with a negligible atmosphere).

APPENDIX F

MATERIAL PROPERTIES DEFINED BY THE PROGRAM

Absorptivities of six Apollo materials for solar radiation and planet radiation were compiled into the BLOCK DATA subprogram B3DATA.[a/] It is possible in general to allow absorptivity for planet radiation to vary with planet temperature. However, in absence of any data on this temperature dependence, constant values were compiled into the program.[b/] The following table gives these values. Coatings 7-16 are undefined.

Coating Number	Absorptivity Solar	Absorptivity Planet	Identification	Apollo S/C Application
1	0.16	0.40	SiO on Aluminized Mylar	Command Module
2	0.25	0.25	Aluminum-filled Polyester	Service Module
3	0.18	0.92	Zinc Oxide Potassium Silicate	ECS and EPS Radiators
4	0.18	0.45	Schjeldahl on Aluminum	LEM Ascent Panels
5	0.18	0.18	Schjeldahl	LEM Descent Panels
6	0.9	0.9	Black	---

---

a/ The six materials, which were specified by the NASA Project Engineer, were considered to be representative of the Apollo as of April 1966; therefore, they are not necessarily applicable to more recent or final designs.

b/ The cross references compiled were all zero; hence $f_s(t)$, $f_p(t)$ and $g(\delta)$ are considered to be unity.

APPENDIX G

PROGRAM ORGANIZATION AND FLOW CHARTS

The main program (deck name OVERLG) calls three subroutines EDITIP, PILOT and PLOTHT, which overlay one another.

Subroutine EDITIP reads the input data and produces an edited input file on logical tape 4. Subroutine PILOT reads data from tape 4, computes heat loads, and writes results on the output unit. If SC-4020 plots are requested for any of the cases run, an intermediate binary tape, logical 8, is written which contains all necessary information for the plots. Subroutine PLOTHT reads logical tape 8, extracts the necessary data and generates output on logical tape 17 which the SC-4020 needs to produce the desired plots.

Brief descriptions of all nonlibrary subroutines, functions, and BLOCK DATA programs are given below. These descriptions are followed by flow charts of the more complex routines.

Subroutines

ANGLET finds the angles which give the inner and outer ring of points used in computing an average shadow factor with respect to radiation from the planet.

ARRANG reads data from arrays on the intermediate plot tape (logical 8) and stores them in arrays representing the curves to be plotted.

BETA90 computes sun-shade points for orbital cases where the sun is in the orbital plane.

COPY sets the 3 x 3 matrix determined by the second argument equal to that determined by the first.

DDFERI is a double precision quartic factorization program from the SHARE library.

DDVETA is a double precision cubic factorization program from the SHARE library.

DIRECT completes construction of the coordinate transformation matrices necessary to find the angles required for configuration factor and shadow factor calculations. Subroutine TRANS begins the matrix construction.

EDITIP reads the data furnished by the user and produces a revised input tape which is read by subroutine TINPUT. Areas and defining angles for Apollo nodes are supplied and if one of the six Apollo configurations is being run for which a particular node is not exposed, this node is flagged to suppress calculation of heats. For cases involving a large number of nodes, the case is subdivided since machine storage is insufficient to store shadow tables for all nodes at once.

FIND locates the sun-shade points, ϕ_{in} and ϕ_{out}, for orbital missions. If the sun is in the orbital plane, BETA90 is called. Otherwise QUART is called to determine the X_p coordinates and WYE to find the Y_p coordinates. Each point is checked to insure that it satisfies the orbit and shadow equations and to insure that it is not on the sunward side of the planet.

GEOFAC interpolates in tables of configuration factors to find a value corresponding to given ϵ , ϕ_c , θ_s and altitude. For values of these parameters outside the range of tabulated entries, the program extrapolates.

HEAT finds heat loads on each element under consideration for a given vehicle position and orientation. Subroutine HOUT is called to print heat loads and if heat loads of any of the elements are to be plotted, these are stored on intermediate tape (logical 8) by subroutine PLOUT.

HOUT prints heat loads out in tabular form.

INIT adjusts the quadrants of ϕ_o , ϕ_{in} and ϕ_{out} for orbital missions so that $\phi_{in}<\phi<\phi_{out}$ whenever the vehicle is in the shade. It also determines whether the vehicle is initially in the shade.

INTERP finds values of $b_m(T)$ for specified temperature by linear interpolation in tables stored internally. The value found by this routine is multiplied by FTIME to find α_p.

JDGEN finds the number of days and fractions of a day since January 1, 1900, at midnight for orbital missions where calendar date and time are read in. This result is used to determine RA and DEC.

LOCUS calculates time and altitude from a given value of true anomaly, ϕ , for orbital missions. It also determines planet temperature if the variable planet temperature option is being run.

LOOP controls the vehicle motion on orbital missions. It causes the vehicle to advance with steps of $\Delta\phi$ in a counterclockwise motion from starting position ϕ_o . When sun-shade points are passed, the step is broken to pick up these special points. Subroutine HEAT is called for each position of the vehicle and printed and/or plotted output results for each vehicle element.

LOOPTJ controls the vehicle motion on trajectory tape missions. It first locates the desired trajectory on the trajectory tape and then reads a tape record for each point. It can interrupt the trajectory if control information so indicates and return to the input routine to determine new parameter values required for the trajectory continuation. LOOPTJ finds some components of the coordinate transformation matrices needed for determining angles used in configuration factor and shadow factor calculations. For each point of the mission, subroutine HEAT is called and printed and/or plotted results are generated for each vehicle element.

MIDENT stores a 3 x 3 identity matrix in the array given by its argument.

MOON finds parameters analogous to right ascension and declination, which determine sun position, as a function of date for lunar orbits.

OVERLG is the main program which serves only to control program overlay.

PILOT controls the main computation. It converts configuration factor tables to floating point form and controls the principal subroutines TINPUT and LOOP or LOOPTJ.

PLANET finds parameters analogous to right ascension and declination, which determine sun position, as a function of date for orbits around Mercury, Venus and Mars.

PLOTHT reads the intermediate plot tape (logical 8), extracts control information and identification, then calls ARRANG to set up tables of values to be plotted and POINTS or PUNKTE to generate the SC-4020 plot tape (logical 17).

PLOUT writes a buffer load of points to be plotted on tape 8, the intermediate plot tape.

POINTS or PUNKTE[a] controls plotting of points put into arrays by subroutine ARRANG.

QUART stores coefficients of the quartic equation for the x-component of the sun-shade point and calls DDFERI.

RADEC finds right ascension and declination from the date for earth orbits.

---

a/ This routine was originally named POINTS, but during adaption of the program for the DCS, conflict with one of the library subroutines was encountered.

SBTRAJ finds the sine and cosine of $\sum$ and β or $\sum^*$ and β^* from trajectory tape data.

SETANG finds the weight factors and indices to be used for calculating planet shadow factors.

SIGBET finds sun-shade points for orbital missions. Unless $\sum$ and β are read in, they are first calculated from other data defining sun-position.

TINPUT reads input for each case, converts units where necessary, calculates a few parameters which do not change during the case, and writes out information defining the case. This routine also controls sun-shade point calculations for orbital missions and part of the coordinate transformations.

TJFIND reads in the identification record from the trajectory tape. A stub is provided in this routine to facilitate conversion to allow more than one trajectory to be stored on the trajectory tape.

TPOINT reads the trajectory tape and returns with values for time, vehicle position, sun position and a code indicating whether the vehicle is in the planet umbra.

TRANS generates matrices describing vehicle roll, pitch and yaw, and the parts of the rotation matrix which are independent of time. For orbital missions it also generates part of the transformation matrix for converting from planet-oriented to sun-oriented coordinates.

TRNSPS transposes a 3 x 3 matrix.

TURNCW rotates a 3 x 3 matrix around one of the coordinate axes. The first argument is the name of the matrix to be rotated. The second argument is the cosine of the angle of rotation. The third argument is $\pm$ sine of the angle of rotation, depending on the sense of the rotation. The last argument denotes the axis of rotation, where x , y and z axes are designated 1, 2 and 3, respectively.

WYE finds y-coordinates of orbital sun-shade points for which the x-coordinate has been found by factoring a quartic equation.

Functions

ARCOS finds the arcosine in degrees of the argument. ARCOS is always from zero to 180 inclusive.

FRI finds a ratio $\frac{r}{R}$ which is needed in determining an angle α between the centerline of a source vector cone and either the inner or outer ring of points used in computing average planet shadow factors. The angle α is given by $\alpha = \arctan\ (\frac{r}{R}\ \tan\ \alpha_m)$. (See Appendix B of the Task 2 report.)[5]

FTEMP finds the factor of α_s or α_p expressing dependence on time. Nominal value for FTIME is 1.

MANDN gives the logical AND of its two arguments, i.e., the function gives a one bit in each position where both arguments have a one bit and a zero bit elsewhere.

MERGE gives the logical OR of its two arguments, i.e., the function gives a zero bit in each position where both arguments have a zero bit and a one bit elsewhere.

NCOAT extracts the coating code from the packed words in the LPACK array.

SHADOW finds shadow factors with respect to solar radiation if the first argument is positive. It if is zero, the program chooses an algorithm and determines some constants that will be used in finding shadow factors.

SHPLAN finds effective shadow factors with respect to planet radiation and albedo.

UNSHAD returns the desired shadow factor from a word which has nine shadow factors packed together.

BLOCK DATA Programs

DATAB1 and DATAB2 (alternate names: B1DATA and B2DATA)[a] define the table of configuration factors as functions of altitude, ϵ, θ_s and ϕ_c.

DATABE and DATABF (alternate names: BEDATA and BFDATA)[a] define areas and Ω_b and Λ_b for the 950 Apollo surface elements referenced by the program.

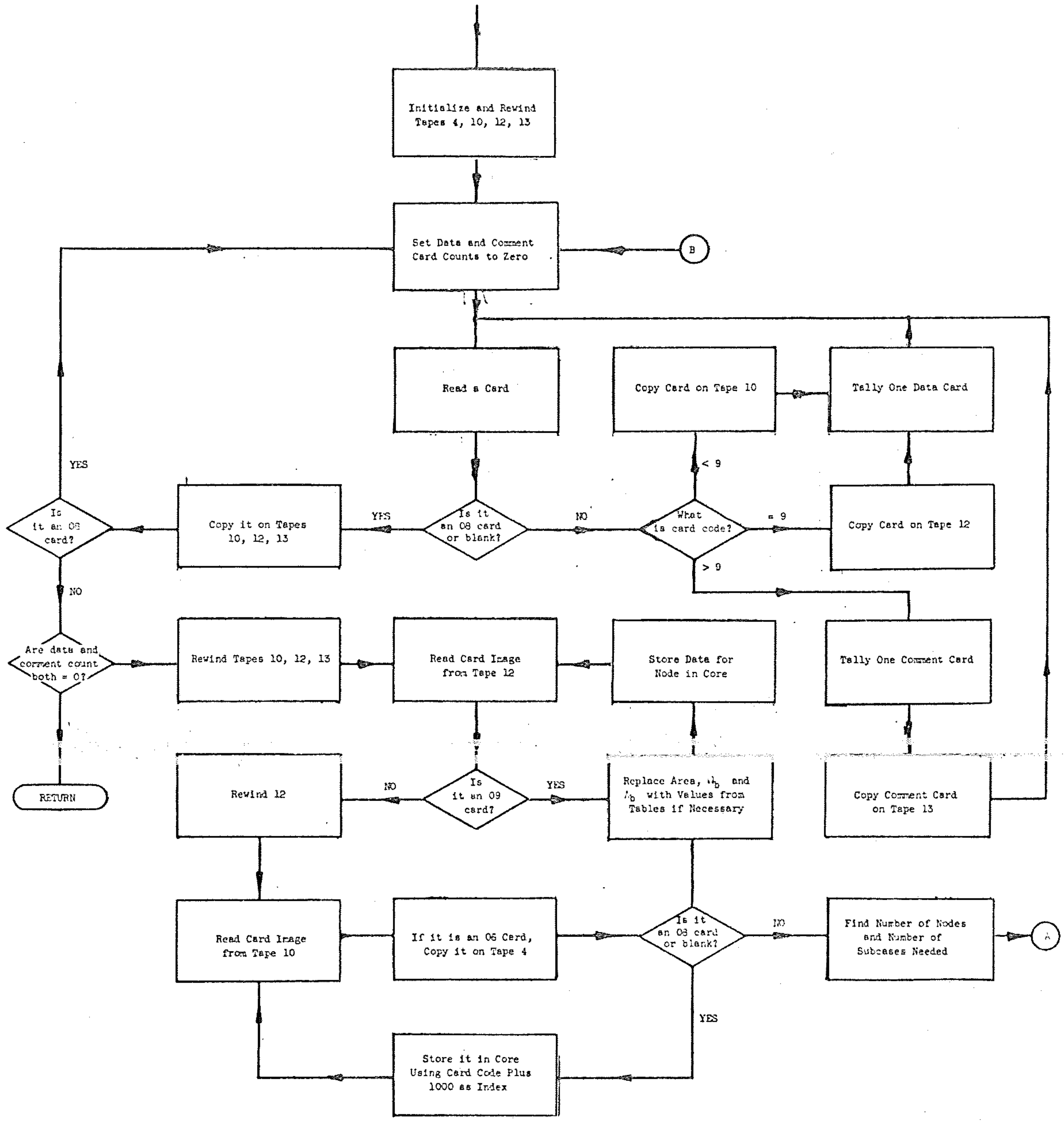
---

a/ Because of ambiguity in object deck sequencing when all these programs begin with the same four symbols, it would be advisable to use the alternate names if the programs are ever recompiled.

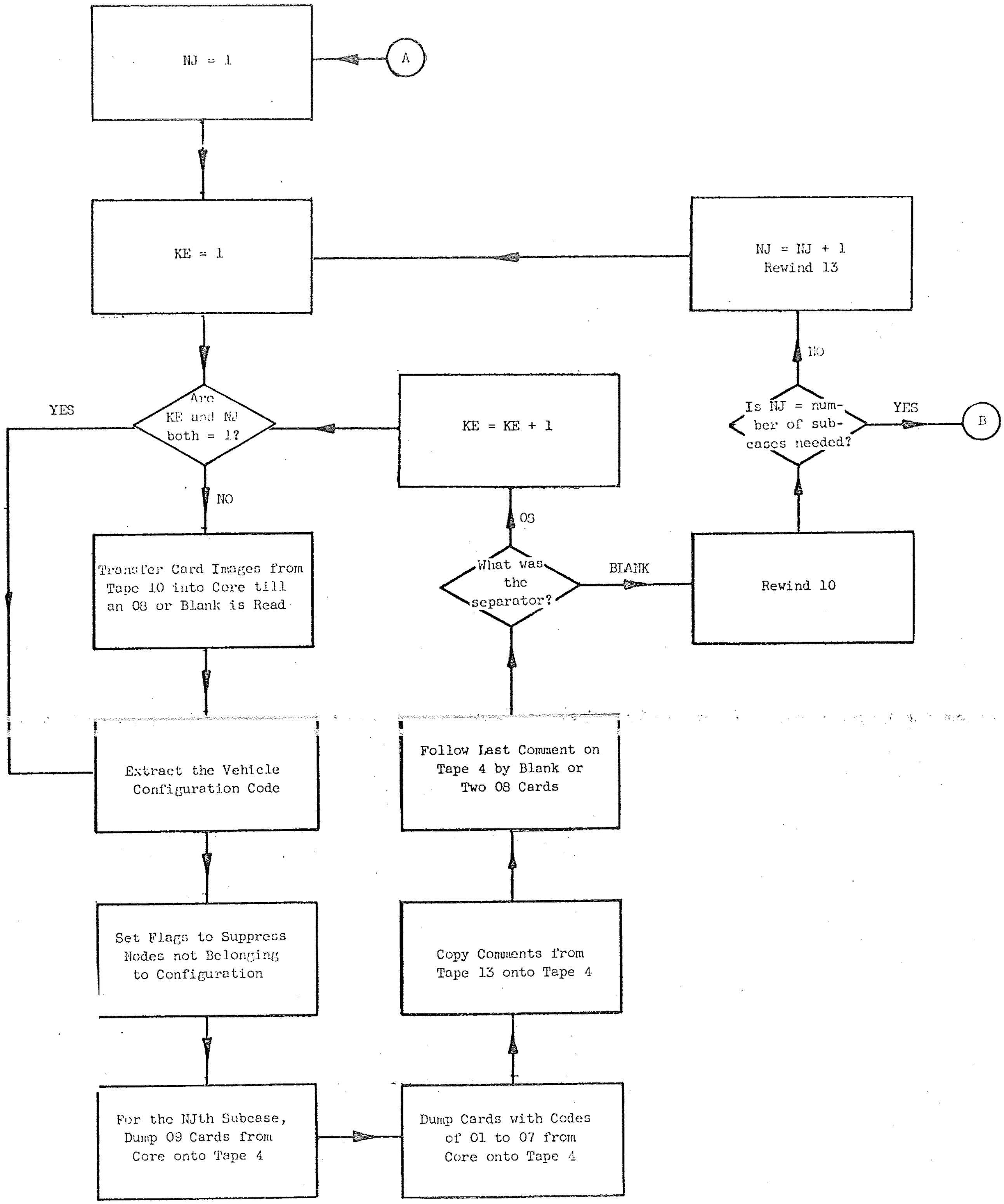
DATAB3 (alternate name: B3DATA)[a] defines miscellaneous data which appear in common storage. Among data included are several useful constants, masking words used in packing and unpacking words, and alphameric arrays used in headings. The solar constant and tables of material properties are also defined, as well as data describing the moon and all planets except Pluto.

---

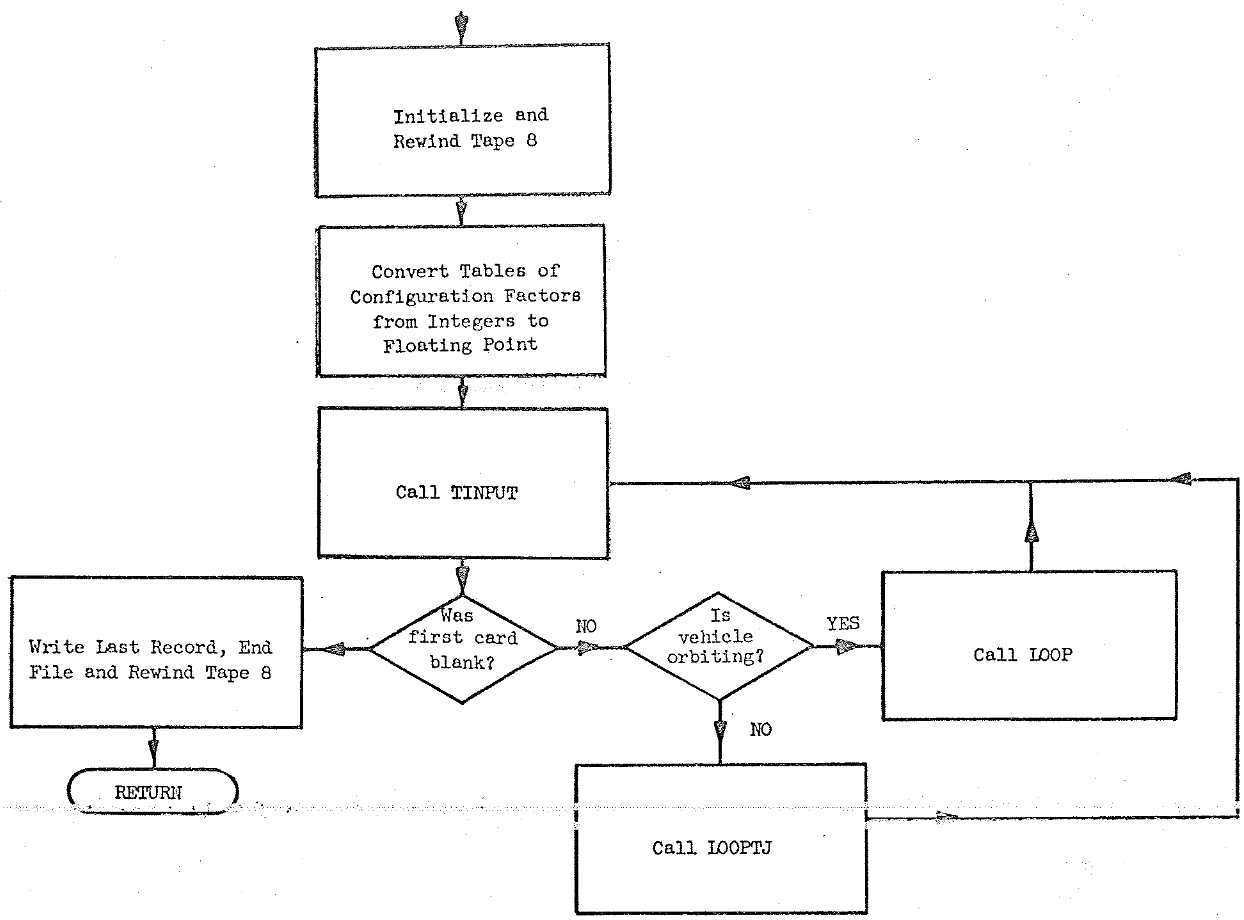
a/ Because of ambiguity in object deck sequencing when all these programs begin with the same four symbols, it would be advisable to use the alternate names if the programs are ever recompiled.



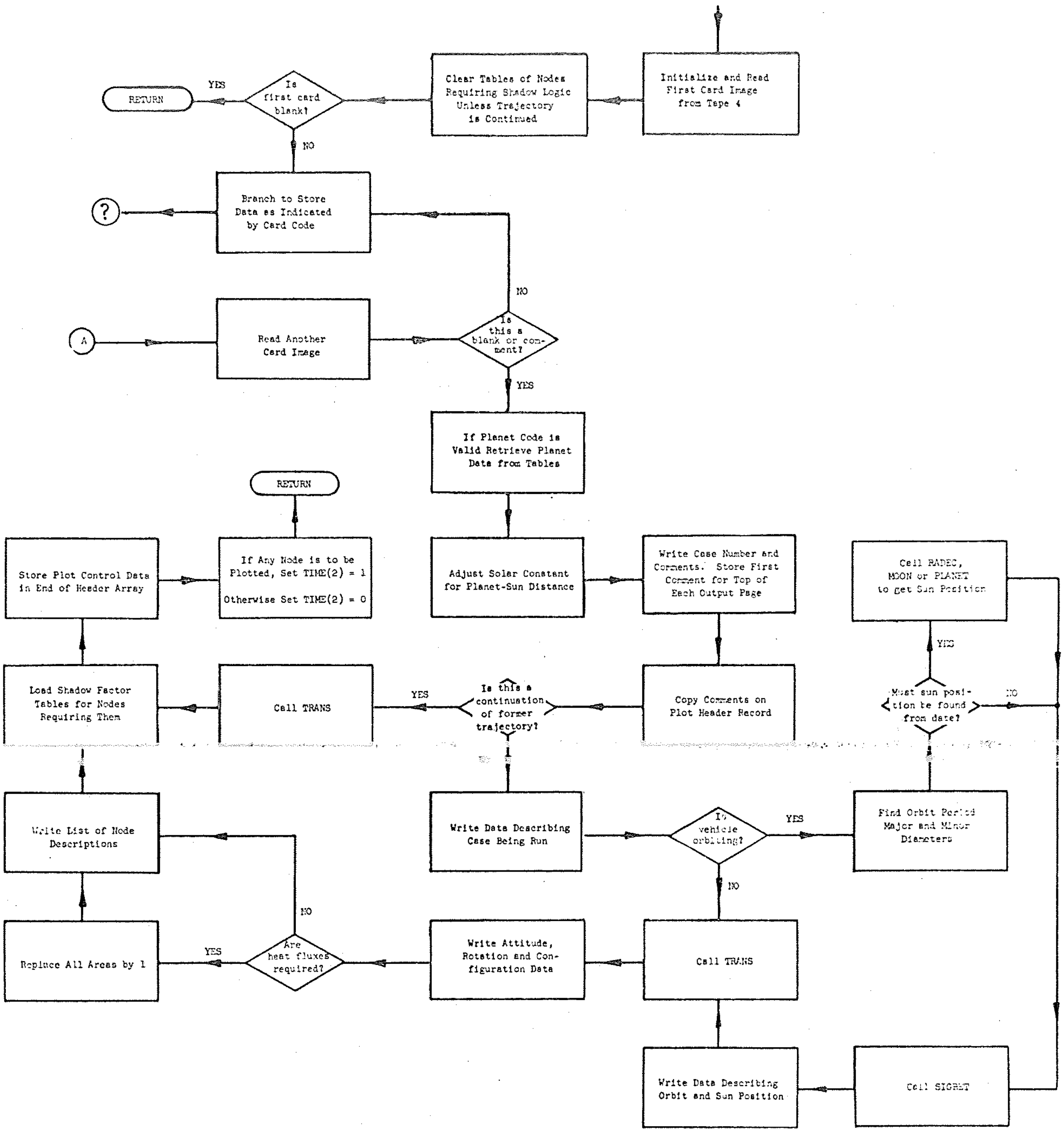
Subroutine EDITIP



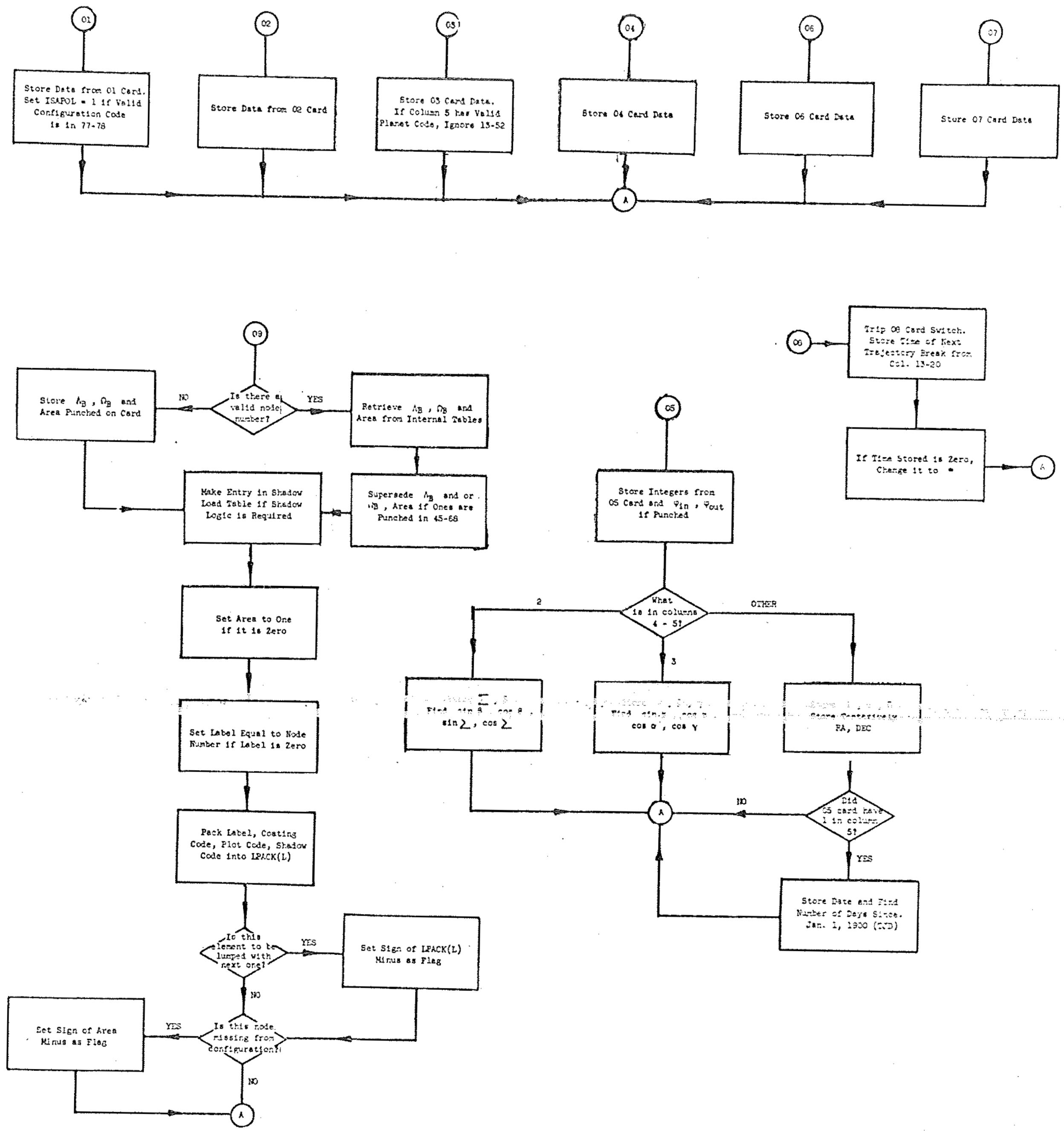
Subroutine EDITIP (Concluded)



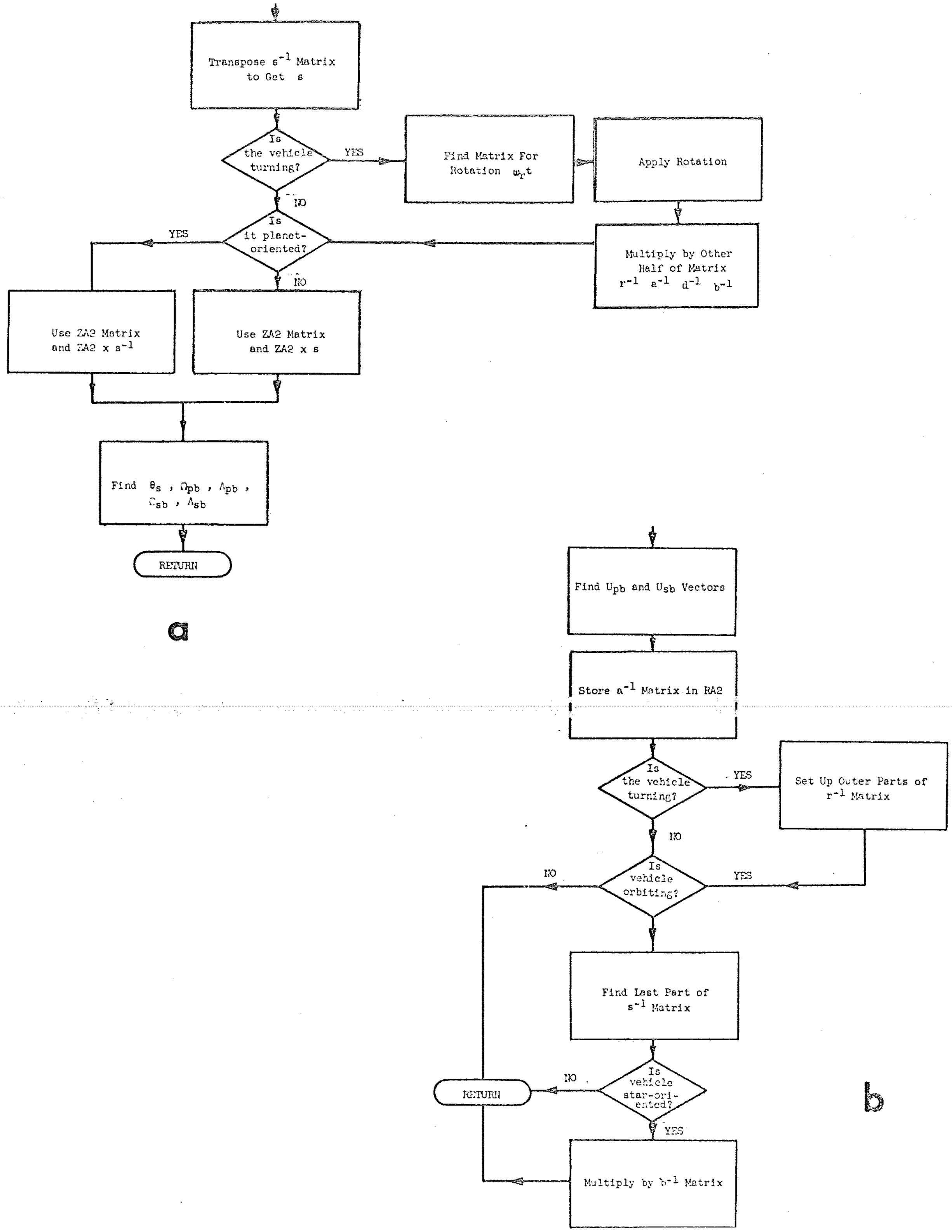
Subroutine PILOT



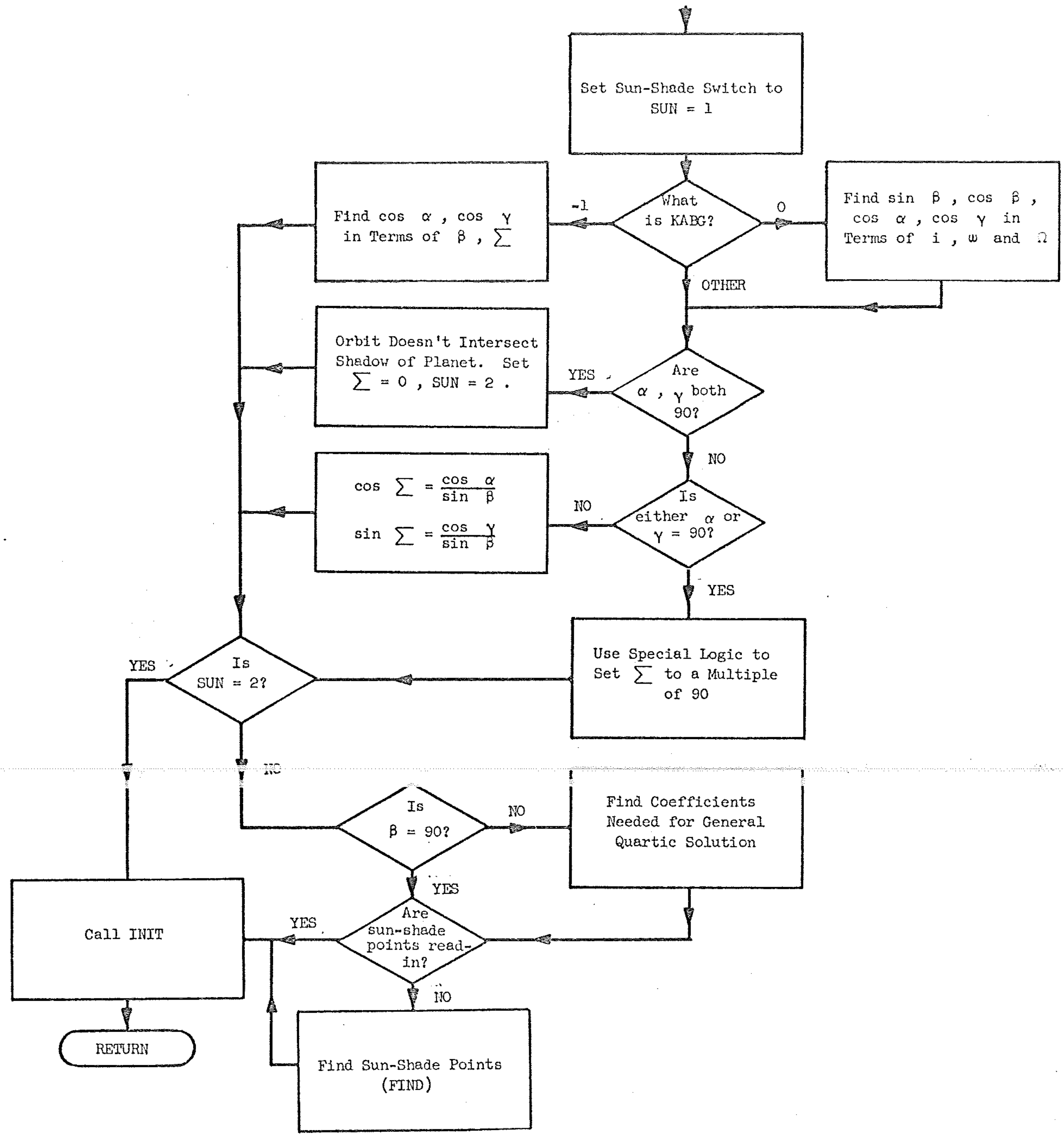
Subroutine TINPUT



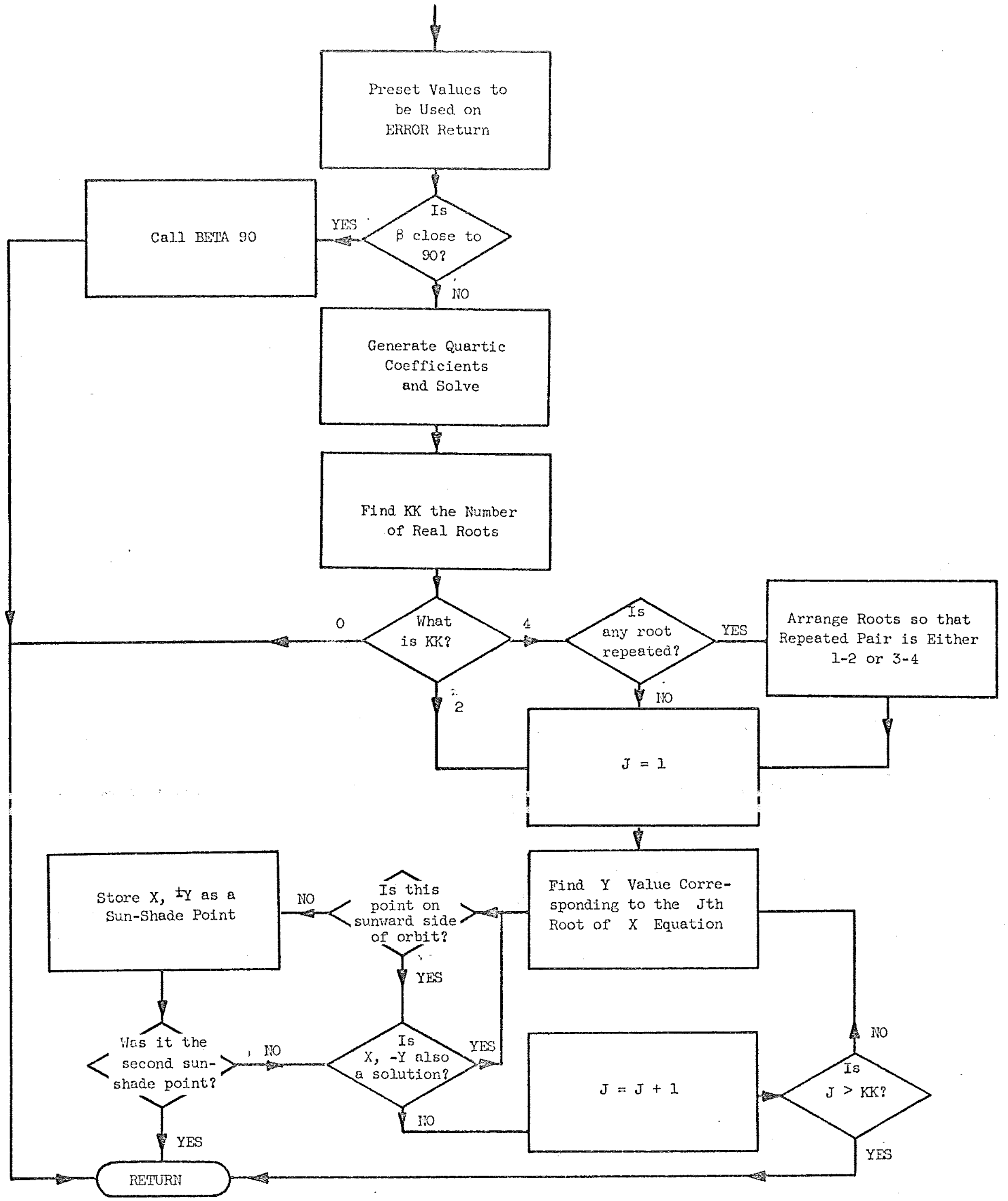
Subroutine TINPUT (Concluded)



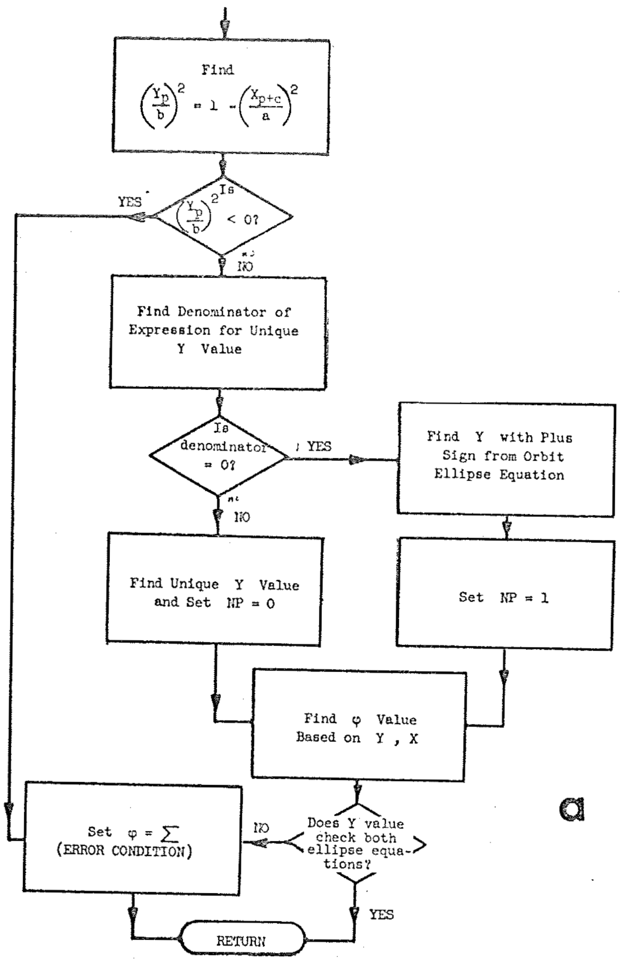
a. Subroutine DIRECT
b. Subroutine TRANS

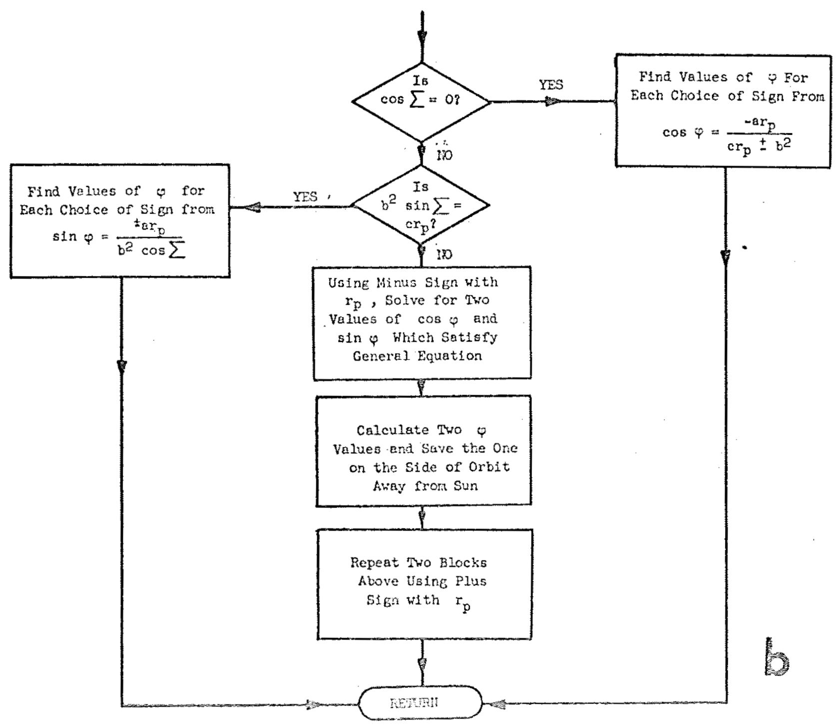


Subroutine SIGBET



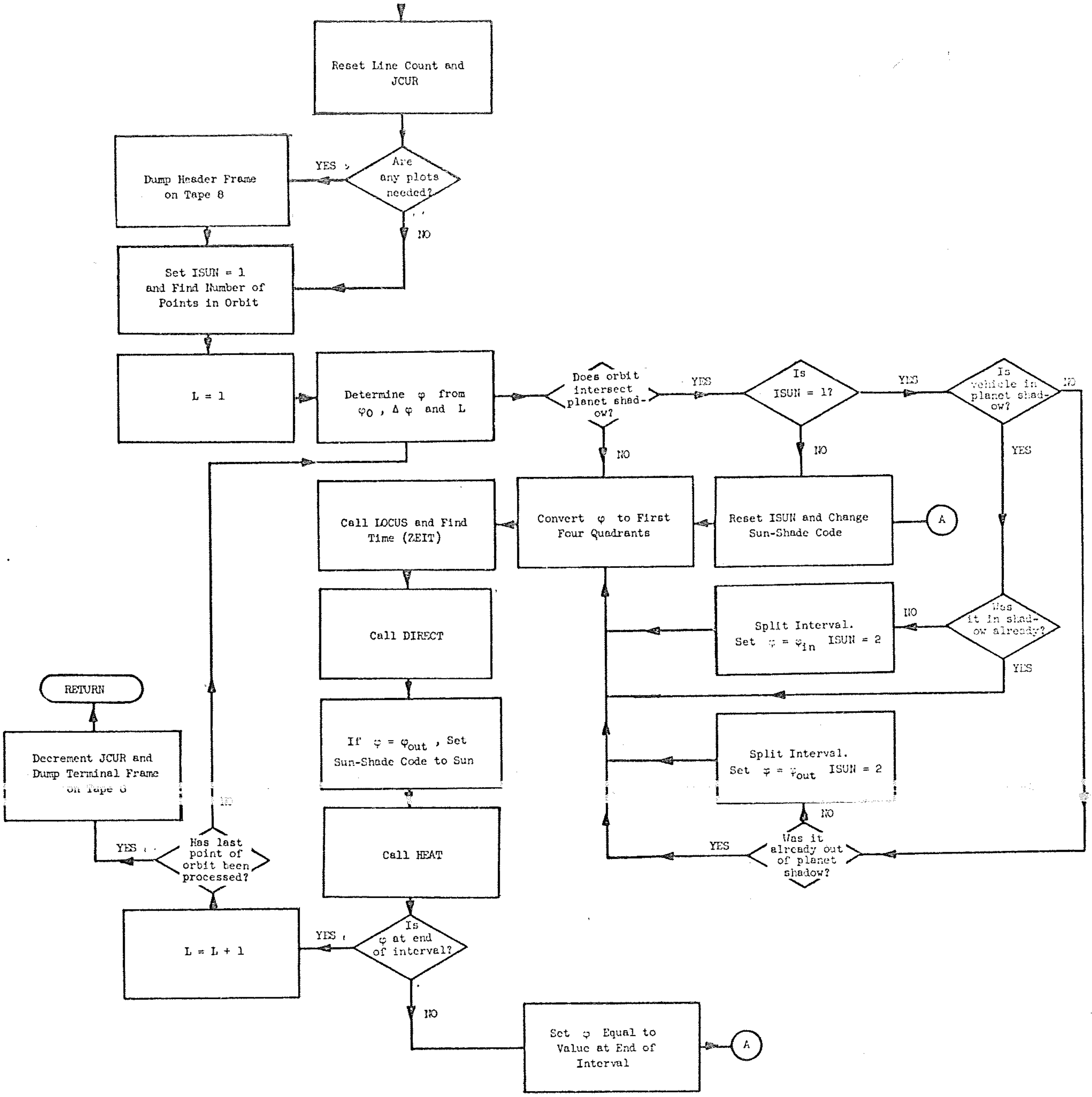
Subroutine FIND



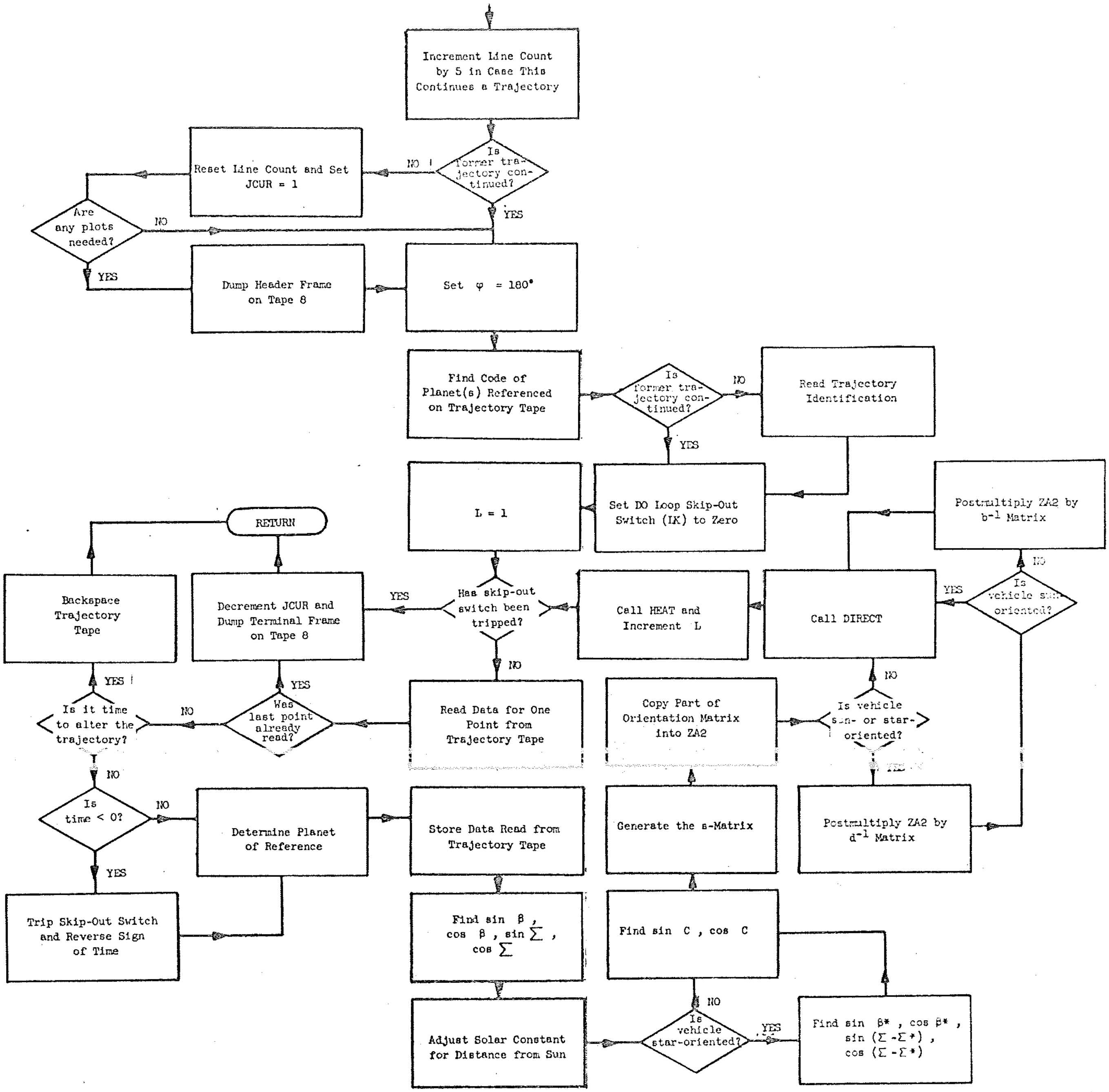


a. Subroutine WYE

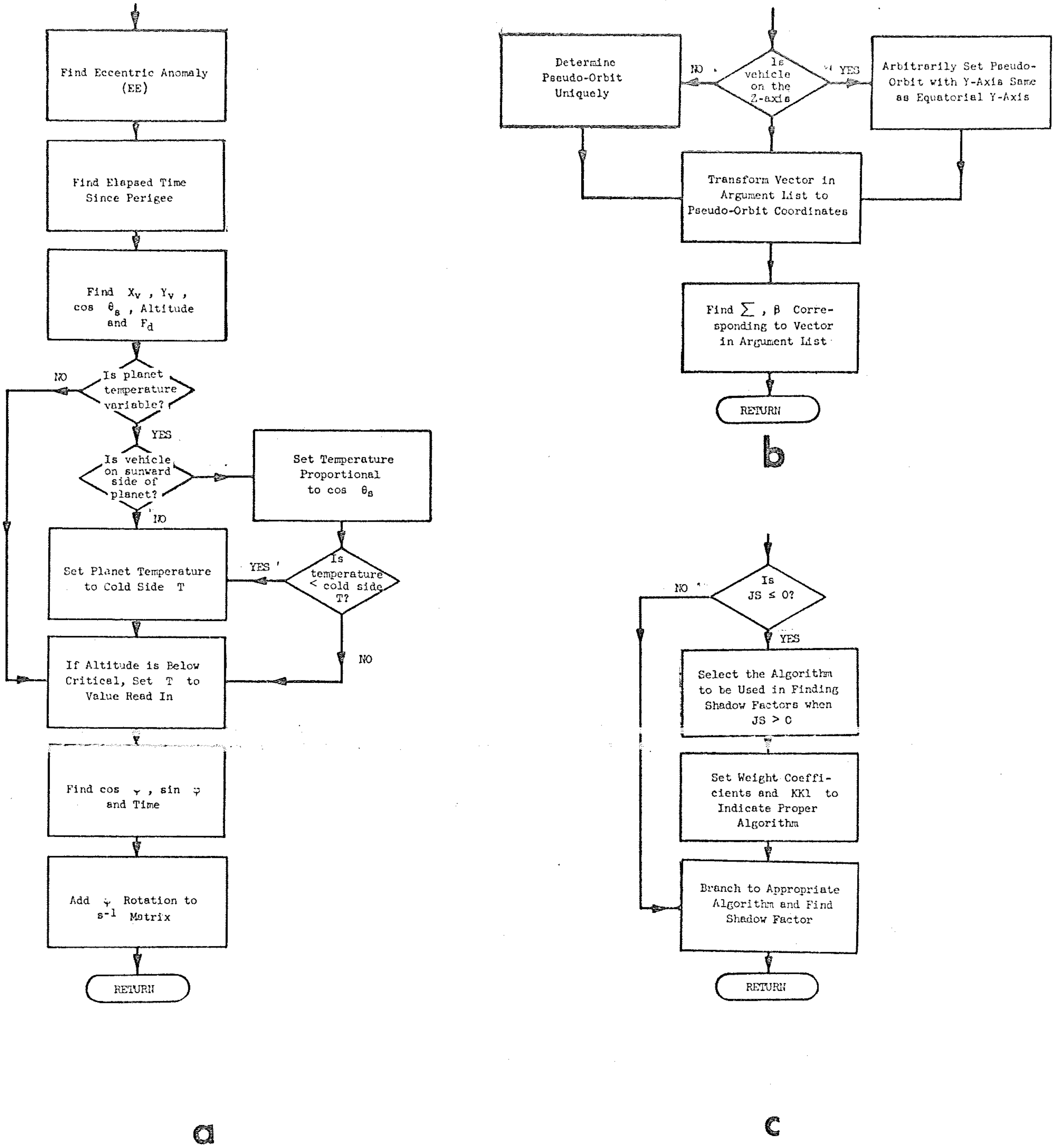
b. Subroutine BETA 90



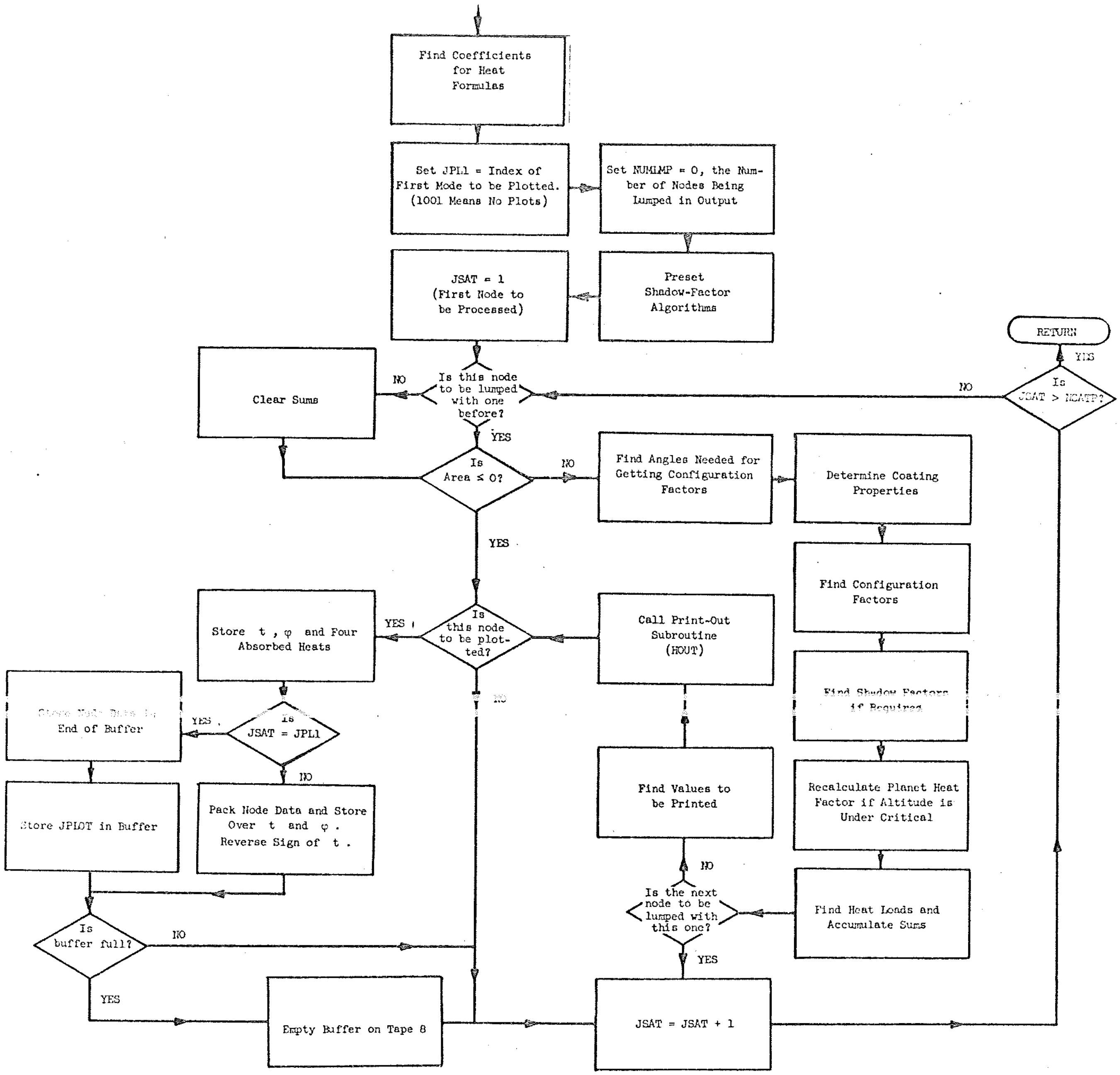
Subroutine LOOP



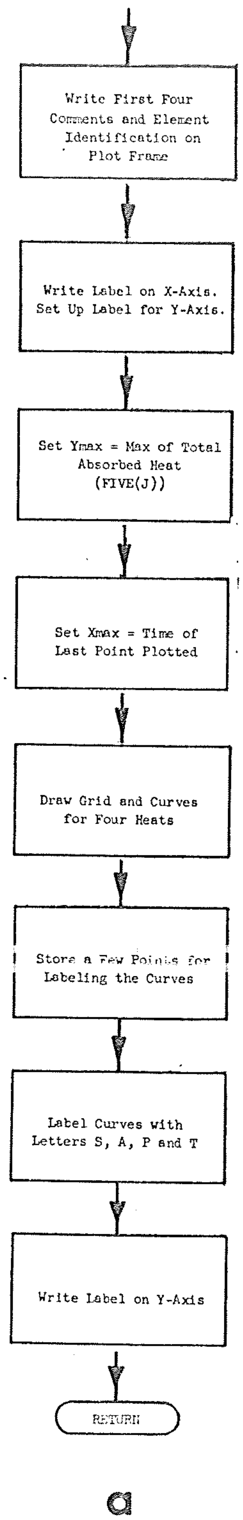
Subroutine LOOPTJ

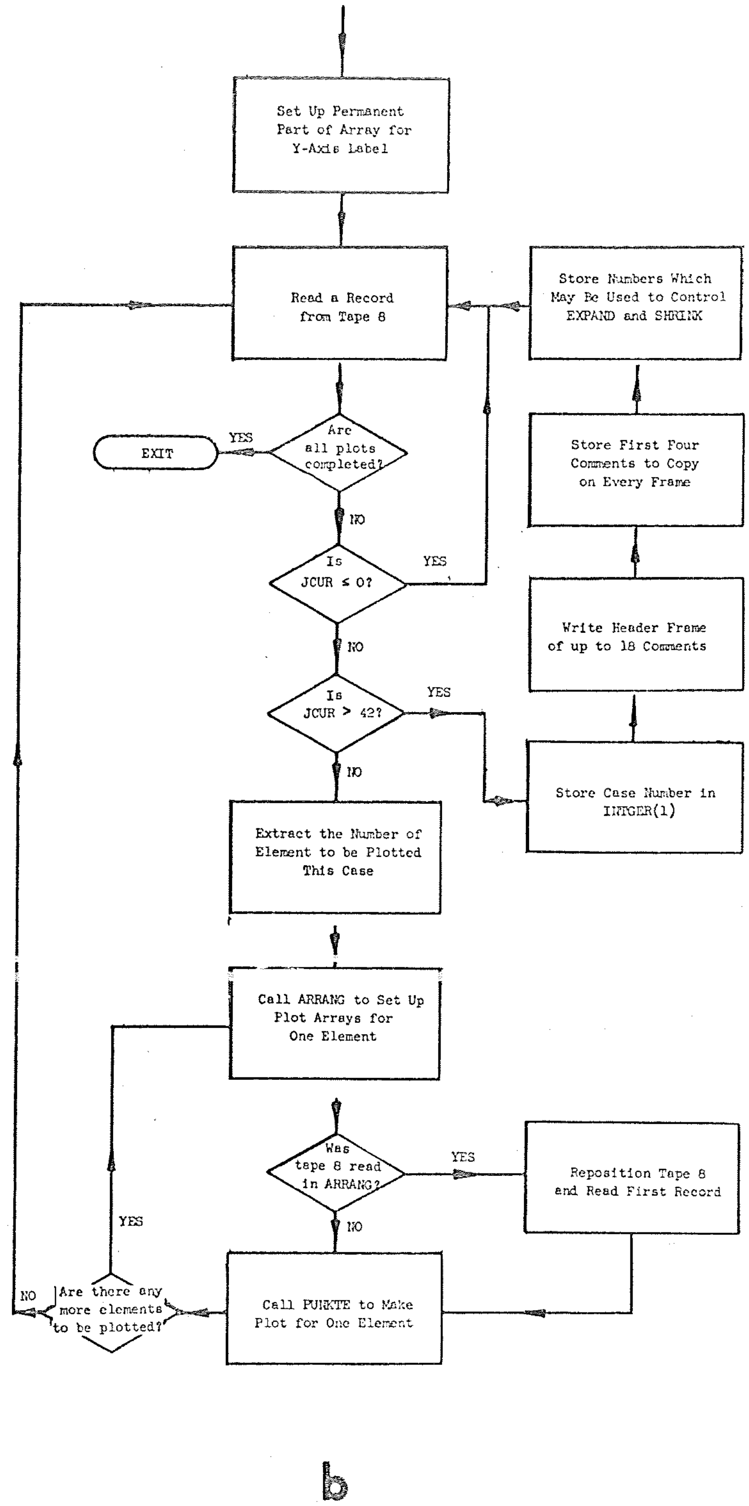


a. Subroutine LOCUS
b. Subroutine SBTRAJ
c. Subroutine SHADOW

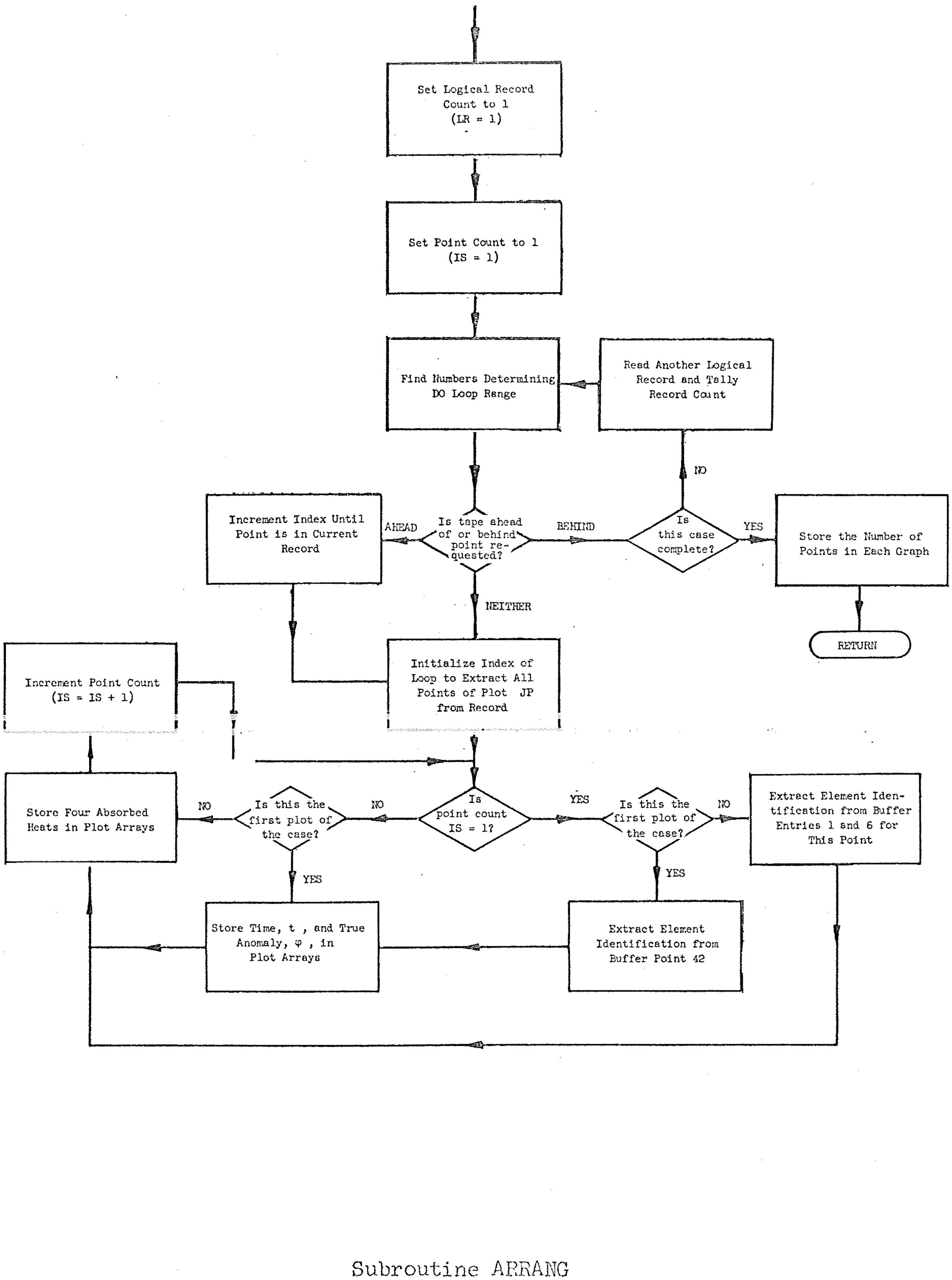


Subroutine HEAT





a. Subroutine PUNKTE
b. Subroutine PLOTHT



Subroutine ARRANG

APPENDIX H

FORMAT OF THE SHADOW FACTOR TAPE

The shadow factor tape contains shadow factors for the six Apollo configurations (see Fig. C-10). For each configuration, shadow factors of all exposed surface elements are given for 128 orientations of the radiating source. The tape format is binary and all records are 190 words long.

The first record of each configuration has a special format. Only the first, second and fourth words are significant. Word four is the integer 15, which indicates that the record identifies the configuration. Word one is the negative of the configuration number. Word two contains a number of the form 40 k + 1, where k is the largest integer such that the first element defined for the configuration in question lies in the range 40 k + 1 to 40 K + 40, e.g., for configuration 1, where the LEM is not included, word two contains 401, where the lowest element number for the command and service modules is 406.

The second record of each configuration contains shadow factors for 10 elements beginning with the element given as word two of the first record. Each table contains 19 words and each word is packed to contain nine 4-bit numbers. The 19 words correspond to 19 angles, Λs_b, ranging from 0° to 360° in steps of 20°. The word for 0° is repeated for 360° in order to avoid any wrap-around interpolation. The nine numbers packed in each work are shadow factors for the associated Λs_b and corresponding to Ωs_b values having cosines of -1.0, -0.75, -0.5, -0.25, 0., 0.25, 0.5, 0.75, 1.0, respectively. The shadow factors corresponding to Ωs_b with negative cosines are stored in the most significant part of the word.

The next record of each configuration contains shadow factors for the next 10 elements, and so forth until the record containing data for elements 941 to 950 is read or until a record is read having the integer 15 in word four, which signals the next configuration.

APPENDIX I

REQUIREMENTS OF SUBROUTINES MANIPULATING TRAJECTORY TAPES

For trajectory tape missions, the program must be able to accurately obtain information from the trajectory tape. Two subroutines, TJFIND and TPOINT, were written to position and read the required information from logical tape 11. The program was debugged using these routines and a dummy trajectory tape.

However, since the principal applications of the trajectory option are expected to be linked with the vehicle ephemeris program written by NASA's Mission Analysis Group, the two original subroutines were replaced by modified routines using data more compatible with the vehicle ephemeris program results. The new routines enable the trajectory data to be written directly from arrays used in the vehicle ephemeris program, and they convert distances from earth radii, as computed by the vehicle ephemeris program, to nautical miles, as required by the heat flux program. The new subroutines were checked out using data generated by the vehicle ephemeris program in use at NASA in March 1966.

Since the NASA vehicle ephemeris program is occasionally modified, the routines for reading trajectory data are subject to change. Hence, instead of a detailed description of the specific routines delivered with the program, the general requirements of these two routines, TJFIND and TPOINT, are given below. This information will allow the user to write equivalent routines for matching the heat flux program to later versions of the NASA vehicle ephemeris program or to any other program which might be used to generate a vehicle trajectory. The general requirements of TJFIND and TPOINTS follow:

1. TJFIND must have two arguments, the first, a single variable and the second a fourteen word array.

2. The first argument should not be redefined during execution of TJFIND.

3. The second through the thirteenth words of the fourteen word array should contain valid alphameric characters which can be used as trajectory identification on printed and plotted output.

4. TPOINT must have two arguments, the first, a fourteen word array of real, i.e., floating point numbers, the second a single integer, namely, the configuration code.

5. The second argument should not be redefined during execution of TPOINT.

6. Upon return from TPOINT the fourteen word array should contain the following numbers. All distances must be in nautical miles.

a. Word 1 should contain time since start of mission in minutes unless this is the last point of the trajectory, in which case it should contain time with the sign reversed.

b. Words 2 to 4 should contain the X, Y, and Z coordinates of the vehicle in the earth equatorial system with origin at the center of the "first" planet.

c. Words 5 to 7 should contain the X, Y, and Z coordinates of the sun in the earth equatorial system with origin at the center of the "first" planet.

d. Words 8 to 10 should contain the X, Y, and Z coordinates of the vehicle in the earth equatorial system with the origin at the center of the "second" planet.

e. Words 11 to 13 should contain the X, Y, and Z coordinates of the sun in the earth equatorial system with origin at the center of the "second" planet.

f. Word 14 should contain floating point one (1.) if the vehicle is in the umbra of either planet. Otherwise it should contain zero.

The "first" and "second" planets correspond to the codes punched in columns 9 and 10, respectively, of the 04 card. Vehicle and sun positions at each point are actually needed only with respect to the planet of reference (corresponding to column 5 of the 03 cards). No harm will be done if zeros or other inapplicable data replace the data with respect to the "other" planet.

APPENDIX J

REFERENCE GUIDE FOR INPUT DATA PREPARATION

A list is given on the following pages summarizing the various data that might be punched as program input data. For each type of card a description is given of all applicable fields. Page numbers referencing additional information in this manual are also given. If the entry under "Applicability" is blank, the field in question may pertain to all kinds of cases. If there is an entry under "Applicability", however, the field is pertinent only for the type of case designated. For all other types of cases the field is not applicable, i.e., it can be left blank. Note that the entire 05 card is not applicable to trajectory tape missions and can be omitted in such cases. Likewise the 08 card is not applicable to orbital missions.

The formats listed are those used by the program; however, for all fields specified as E8.1 it is advisable to punch the number with a decimal point but with no exponent unless the magnitude of the number is so large or so small as to require exponents. For example, one (1) in this format could be punched as "0.1E 01" , but fewer errors would be made if it were simply punched as "1.0" anywhere in the eight-column field. (See sample cards in Fig. 1.) Numbers in I format must be right justified in their appropriate fields.

CASE NUMBER AND CONTROL INFORMATION (01 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=01).	
3 - 5	I3		Case number.	
9 - 12	I4		Number of elements to be analyzed ($1 \leq n \leq 1000$).	
13 - 20	E8.1	Orbital	ϕ_o , the initial value for true anomaly.	49
21 - 28	E8.1	Orbital	$\Delta\phi_o$, the increment of true anomaly at which heat fluxes are calculated.	
37 - 44	E8.1	Traj. tape	First time (min.) in which program parameters are to be instantaneously changed.	
78	I1		Configuration number (1-6) if Apollo shadow factors stored on tape are required for this case. (Shadow tape must be mounted when a valid configuration number is used.) Blank or 0 is used when no shadow factors are used.	
79	I1		For 0 or blank, only absorbed heats are printed out.	
			For 1, incident and absorbed heats are printed out.	
80	I1		For 0 or blank, fluxes in BTU/hr-ft^2 are printed out.	
			For 1, products of fluxes and element areas in BTU/hr are printed out.	

ORIENTATION AND ROTATION (02 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=02).	
3 - 5	I3	Rotating	$\Omega_r(°)$, one of angles describing axis of vehicle rotation.	53
6 - 8	I3	Rotating	$\Lambda_r(°)$, one of angles describing axis of vehicle rotation.	53
9 - 12	I4		For 1, vehicle is planet oriented.	
			For 0, vehicle spins rapidly about random axes.	
			For -1, vehicle is sun-oriented.	
			For -2, vehicle is star-oriented.	
13 - 20	E8.1		$\rho(°)$, vehicle roll angle.	52
21 - 28	E8.1		$\psi(°)$, vehicle pitch angle.	52
29 - 36	E8.1		$\eta(°)$, vehicle yaw angle.	52
37 - 44	E8.1		ω_r(rph) , rate of vehicle rotation. Blank or 0. is used when vehicle is not rotating.	
45 - 52	E8.1	Star-oriented	X-component of a vector pointing to orientation star.	
53 - 60	E8.1	Star-oriented	Y-component of a vector pointing to orientation star.	
61 - 68	E8.1	Star-oriented	Z-component of a vector pointing to orientation star.	

PLANET (03 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=03).	
3 - 5	I3		For 1 to 9, number is taken as planet code.	60
			For 0 or blank, planet data are read from columns 13 - 52.	
13 - 20	E8.1	Unknown planet	Distance from planet to sun in nautical miles.	
21 - 28	E8.1	Unknown planet	Planet radius in nautical miles.	
29 - 36	E8.1	Unknown planet	Planet albedo.	
37 - 44	E8.1	Unknown planet	GM_p (ft^3/sec^2), gravitational constant times planet mass.	
45 - 52	E8.1	Unknown planet	Adjusted cold side temperature (°R).	

MISSION (04 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=04).	
3 - 5	I3		For 0 or blank, trajectory tape mission is to be run.	
			For 1, orbital mission is to be run.	
6 - 8	I3	Orbital	Number of degrees of true anomaly for which program computes.	49
9	I1	Traj. tape	Planet code of first trajectory tape planet of reference.*	
10	I1	Traj. tape	Planet code of second trajectory tape planet of reference.*	
13 - 20	E8.1	Orbital	Apogee in nautical miles.	
21 - 28	E8.1	Orbital	Perigee in nautical miles.	

* Unless new routines are written to manipulate the trajectory tape (see Appendix I) the planet codes are 1 and 2, respectively.

SUN POSITION (05 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2	Orbital	Card code (=05).	
3 - 5	I3	Orbital	A code to specify sun position input option. Value must be 1, 2, 3 or 5. The code instructs the program how to interpret data in 13 - 76.	
6 - 8	I3	Orbital	For 1, sun-shade points ϕ_{in} and ϕ_{out} are read from columns 61 - 76. Otherwise they are computed.	
13 - 20	E8.1	Orbital	Angle $i(°)$ if column 5 contains 1 or 5.	51
			Angle $\sum(°)$ if column 5 contains 2.	50
			Angle $\alpha(°)$ if column 5 contains 3.	50
21 - 28	E8.1	Orbital	Angle $\omega(°)$ if column 5 contains 1 or 5.	51
			Angle $\beta(°)$ if column 5 contains 2 or 3.	50
29 - 36	E8.1	Orbital	Angle $\Omega(°)$ if column 5 contains 1 or 5.	51
			Angle $\gamma(°)$ if column 5 contains 3. Otherwise blank.	50
37 - 44	E8.1	Orbital	Angle RA(°) if column 5 contains 5.	50
			Year if column 5 contains 1. Otherwise blank.	
45 - 52	E8.1	Orbital	Angle DEC(°) if column 5 contains 5.	50
			Month if column 5 contains 1. Otherwise blank.	

SUN POSITION (05 CARD) (Concluded)

Columns	Format	Applicability	Description	Ref. Page
53 - 60	E8.1	Orbital	Day of month if column 5 contains 1. Otherwise blank.	
61 - 68	E8.1	Orbital	Hour of day (0 to 23.) if column 5 contains 5. $\phi_{in}(°)$ if column 8 contains 1. Otherwise blank.	
69 - 76	E8.1	Orbital	Minute of hour (0. to 60.) if column 5 contains 5. $\phi_{out}(°)$ if column 8 contains 1. Otherwise blank.	

REDEFINITION (06 CARD)

Columns	Format	Applicability	Description	Ref. Page
		(Subcase with 3, 4, 5 or 6 in column 12)		
1 - 2	I2		Card code (=06).	
3 - 5	I3		Index of first table entry on card.	
6 - 8	I3		Index of last table entry on card.	
9 - 12	I4		Code describing type of table being defined. Code 3 indicates f_s versus t . Code 4 indicates f_p versus t . Code 5 indicates g versus δ . Code 6 indicates b_m versus T .	
13 - 76	8E8.1		Table entries to be stored as index ranges from first to last value.	
77 - 78	I2		Number of table being defined (from 1 to 16).	
		(Subcase with 7, 8 or 9 in column 12)		
1 - 2	I2		Card code (=06).	
3 - 5	I3		Material code (from 1 to 16).	
6 - 8	I3		Corresponding table numbers (from 1 to 16)	
9 - 12	I4		Code describing type of table assignment. Code 7 indicates assignment of f_p versus t table. Code 8 indicates assignment of f_s versus t table. Code 9 indicates assignment of g versus δ table.	

REDEFINITION (06 CARD) (Concluded)

Columns	Format	Applicability	Description	Ref. Page
		(Subcase with 10 in columns 11 - 12)		
1 - 2	I2		Card code (=06).	
9 - 12	I4		Subcode (=10) indicating solar constant is redefined.	
13 - 20	E8.1		New value of solar constant.	
		(Subcase with 11 in columns 11 - 12)		
1 - 2	I2		Card code (=06).	
3 - 5	I3		Code of first material referenced on this card.	
6 - 8	I3		Code of last material referenced on this card.	
9 - 12	I4		Subcode (=11) indicating that this card redefines values of α_m for one or more materials.	
13 - 76	8E8.1		Values of α_m for materials with codes ranging from first to last as shown in columns 3 - 5 and 6 - 8.	

LOW ALTITUDE PLANET TEMPERATURE (07 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=07).	
13 - 20	E8.1		Altitude (n.m.) below which planet temperatures computed by the program are superseded by temperature in columns 21 - 28 of this card. For blank or 0. the program always uses computed temperatures. This altitude is understood to be zero unless an 07 card is read to redefine it.	
21 - 28	E8.1		Planet temperature (°R) used by the program when the altitude is below the value in columns 13 - 20 of this card.	

TRAJECTORY CONTINUATION (08 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2	Traj. tape	Card code (=08).	
13 - 20	E8.1	Traj. tape	Cutoff time (min.) for next segment of trajectory. When a time exceeding this value is read from the trajectory tape, the case will be interrupted to read parameters being instantaneously changed.	

ELEMENT (09 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=09).	
3 - 5	I3		Sequence number of element for this problem. The number must be no greater than the number of elements to be analyzed. Elements to be lumped together require adjacent sequence numbers.	
6 - 8	I3		If any of the internally stored element data are needed, the node number for the element must be punched. If this field does not contain a valid node number, area, Λ_n and Ω_n are read from this card, and shadow factors cannot be referenced.	
9 - 12	I4		This field contains a nonzero numerical label which will identify the element in the output listing. If this field is blank or 0 the program uses node number in columns 6 - 8 as label.	
13 - 20	E8.1		Angle $\Lambda_n(°)$ for the element in case values from internal tables are not used.	49
21 - 28	E8.1		Angle $\Omega_n(°)$ for the element in case values from internal tables are not used.	49
29 - 36	E8.1		Element area (ft.^{2}) in case values from internal tables are not used.	

ELEMENT (09 CARD) (Concluded)

Columns	Format	Applicability	Description	Ref. Page
37 - 44	E8.1		For all elements which are to be lumped with succeeding elements, i.e., with elements having succeeding sequence numbers, this field must contain the same label punched in columns 9 - 12 unless they are blank, in which case it must contain the node number from columns 6 - 8. Note that the format here requires a decimal point.	
45 - 52	E8.1		For 1.0 the value of Λ_n in 13 - 20 supersedes the value stored in internal tables. For blank or 0. the value from the internal table is used if a valid node number is given.	
53 - 60	E8.1		For 1.0 the value of Ω_n in 21 - 28 supersedes the value stored in internal tables. For blank or 0. the value from the internal table is used if a valid node number is given.	
61 - 68	E8.1		For 1.0 the value of area in 29 - 36 supersedes the value stored internally. For blank or 0. the value from internal tables is used if a valid node number is given.	
77 - 78	I2		Coating material number.	
79	I1		For 1, shadow factors for this node are loaded from the shadow tape and shadow logic is used to find heat fluxes. For blank or 0, shadow logic is suppressed and factors are not loaded.	
80	I1		For 1, heats will be plotted for this element. For blank or 0, plots will be suppressed.	

COMMENT (10 CARD)

Columns	Format	Applicability	Description	Ref. Page
1 - 2	I2		Card code (=10).	
3 - 80	13A6		Alphameric comment.	

REFERENCES

1. Finch, Harold L. et al., "Orbiting Satellite Surface Temperature Prediction and Analysis," Final Report submitted by Midwest Research Institute under Contract No. NAS9-1059, February 1964.

2. Finch, Harold L., and Duncan Sommerville, "Development of a Computer Program for Determining External Radiation Absorbed by the Apollo Spacecraft," Final Report submitted by Midwest Research Institute under Contract No. NAS9-3860, 1966.

3. Fowle, Frederick E., "Smithsonian Physical Tables," Smithsonian Institute, 1943, p. 606.

4. Ehricke, Krafft A., "Space Flight," D. Van Nostrand Co., Inc., p. 118.

5. Finch, Harold L., and Michael Noland, "Development of a Computer Program for Determining External Radiation Absorbed by the Apollo Spacecraft," MRI Task Report 2, December 1965.